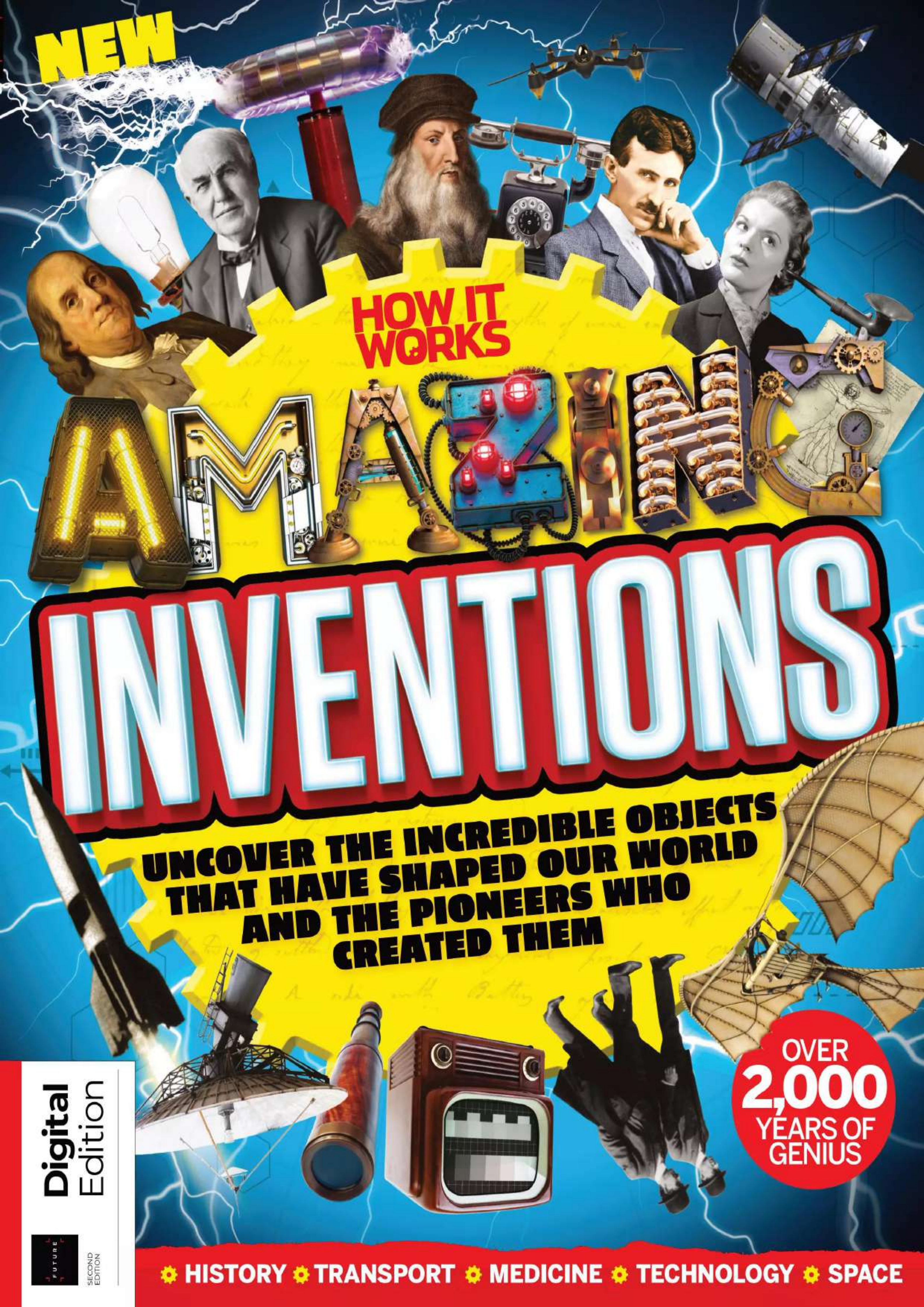
NEW
HOW IT WORKS
AMAZING
INVENTIONS
UNCOVER THE INCREDIBLE OBJECTS THAT HAVE SHAPED OUR WORLD AND THE PIONEERS WHO CREATED THEM
OVER 2,000 YEARS OF GENIUS
Digital Edition
FUTURE
SECOND EDITION
HISTORY • TRANSPORT • MEDICINE • TECHNOLOGY • SPACE

AMAZING INVENTIONS

Innovation is everywhere – it always has been, ever since we first walked the Earth. From the small and seemingly insignificant to the most major inventions, they have all shaped our lives, even if we might not know it. So now it's time to celebrate them.

In How It Works Book of Amazing Inventions, uncover the Roman innovations that are still with us today like the aqueduct as well as the terrifying medical tools that fell out of use (for good reason). Find out who invented the first ever computer, and explore the future of new technologies like virtual reality and artificial intelligence. Hop on the Space Shuttle, the vehicle that took humans into orbit, before we reveal how NASA has contributed to the everyday objects that you can find in your home.

Finally, meet the geniuses behind innovations throughout history, from Leonardo da Vinci and Joseph Lister to Sir Tim Berners-Lee and Hedy Lamarr, as you discover the most amazing inventions. The journey starts just over the page.

AMAZING INVENTIONS

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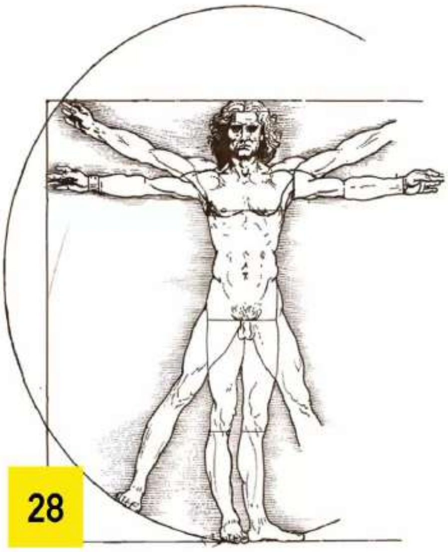

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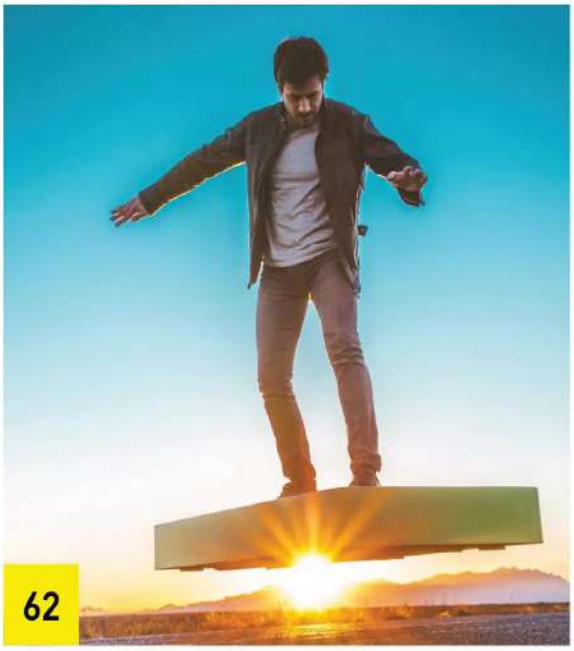

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GREATEST INVENTIONS

FROM THE WHEEL TO THE 3D PRINTER, TAKE A LOOK AT 50 OF HISTORY'S MOST SIGNIFICANT INNOVATIONS THAT HAVE SHAPED THE MODERN WORLD

What is it to be human? That question is hard to answer, but one thing that most would agree plays a large part in it is our creativity. Machines – even revolutionary ones – lack the ability to think outside the box, or to add two and two together and make five. They can often outperform us in many tasks, both physically and mentally. However, the creative element that led to their own existence still remains elusive.

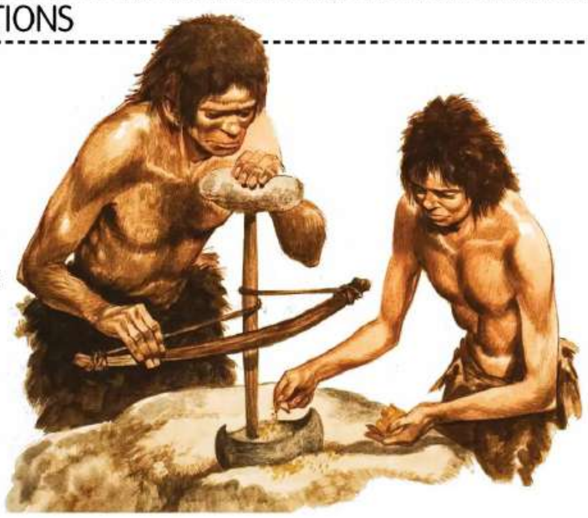
And so it has been throughout time. Human ingenuity has led to the creation of thousands upon thousands of tools, machines, systems, processes and materials that have made our lives easier and helped us better understand the world. From the wheel to the refrigerator, printing press to magnetic compass, humanity has always pushed its creativity to the limit, building devices that – while sometimes seeming insignificant – have gone on to change the world in amazing ways. Of course, not every creative spark has led to the electric light bulb or microscope, but we can nevertheless always learn from our mistakes – sometimes even more than our successes.

Here are just 50 of the millions of inventions that have been produced due to our insatiable hunger to make our lives that little bit easier. You never know, perhaps they'll inspire you to think up some innovations of your own...

1. BASIC TOOLS

2.6 million years ago

Early humans discovered the use of sharp stones early on in the Palaeolithic period and, after identifying their ability to cut and skewer, began artificially sharpening stones of their own accord and fashioning them into primitive weapons. This tool-making evolution enabled us to perform a wide array of tasks that before would have been impossible – or at least much more difficult – such as hunting, skinning animals and cutting wood. The earliest stone tools discovered to date are from 2.6 million years ago; they were unearthed in Ethiopia.



6. GLASS

4500 BCE

Just think, where would we be without glass? Living in much colder or darker homes, that's for sure. Indeed, since its invention some 4,500 years ago in the Bronze Age Middle East, the use of glass became more and more widespread. By the time of the Ancient Romans, glass was no longer a luxury commodity, used by many for bottles and jewellery. Today, this world-changing material features in virtually every building and vehicle on Earth.

4. MAPS

6500 BCE

From a modern perspective it's hard to imagine a time when maps didn't exist, however for thousands of years that was the case, with humans living without them up to around 6500 BCE when the art of cartography emerged in Ancient Babylonia. One of the earliest examples is a wall map found in Çatalhöyük (now in Turkey), clearly showing the layout of the town and the surrounding landscape.

7. GLUE

4000 BCE

While these days we have artificial man-made adhesives, simpler natural glues have been used for thousands of years. Ancient Egyptian carvings that are over 3,000 years old demonstrate the use of glue to stick veneer to sycamore, while many burial sites throughout Europe have 6,000-year-old pottery that has been repaired with plant sap and bark tar. The Ancient Romans even used beeswax glues to fill in the seams of their ships.

2.6 MYA

2. BASIC AGRICULTURE

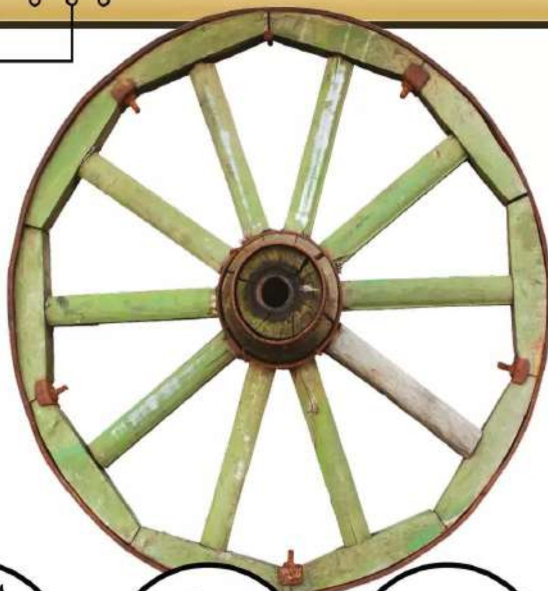
12,000 years ago

The invention of basic farming tools and techniques was vital to the development of civilisation, allowing us to transition from small hunter-gatherer groups into larger, more advanced trading societies. Evidence suggests that around 12,000 years ago planned cultivation was in effect, with specialised tools such as harvesting sickles, while advanced agricultural techniques like irrigation followed later in Mesopotamia circa 6000 BCE.

5. WHEEL

5150 BCE

One of the greatest inventions of all time, the wheel has not only stood the test of time – with the oldest discovered carbon dated to around 7,150 years ago – but transformed every society or industry it has touched. From farming fields 1,000 years ago through to commuting miles into a 21st-century metropolis, the invention of the wheel has made all our day-to-day lives easier



EVOLUTION OF...

3. BOAT

7500 BCE

With 70 per cent of Earth's surface covered in water, there was always a demand for water-going transport – something that was first met in the mid 8th millennium BCE. The earliest boats were dugouts: simple tree trunks hollowed out to form canoe-like vessels. But over the following centuries and millennia, they grew in size and complexity dramatically. Here we pull out some of the boat's evolutionary stages up to the present day...

Canoe

The inevitable evolution of the dugout, the canoe was fashioned around the world by peoples from the Americas, Europe and Oceania.

Chinese junk

Developed in the Han dynasty (206 BCE – 220 CE), this was a wooden, ocean-going transport

Galleon

A multi-decked sailing ship used for transport, trade and combat, the 16th-century galleon became famous for its

Paddle steamer

Combining paddle-wheel propulsion and a steam engine, this became the most popular way to cross oceans in the late

"THE ANCIENT ROMANS USED BEESWAX GLUES TO FILL THE SEAMS OF THEIR SHIPS"

9. WEAVING

3500 BCE

Weaving may not sound like a groundbreaking invention, but when the Ancient Egyptians mastered it back in the 4th millennium BCE, it revolutionised the way we dressed. This early weaving was undertaken on primitive, two-person looms that could only weave a fixed length of cloth. However, by the close of classical antiquity, dexterous horizontal and vertical weaving looms could be found throughout Asia, Africa and Europe (including Ancient Greece, as illustrated). Today, weaving is undertaken on a massive scale by large, shuttleless machines such as rapier and air-jet looms.

KEY PLAYERS

ARCHIMEDES OF SYRACUSE

287-212 BCE

Not only was Ancient Greek polymath Archimedes (of 'Eureka!' moment fame) one of the greatest mathematicians of all time, but he was also one of the greatest inventors. A few of his best- known accomplishments include the Archimedes screw, the claw of Archimedes and the odometer. He was killed before his time during the Siege of Syracuse.

2500 BCE

8. ALPHABETS

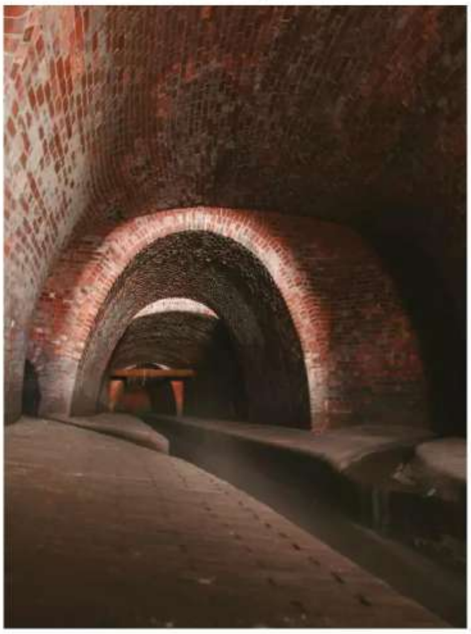
4000 BCE

The phonetic alphabet is believed to have been devised around 6,000 years ago by the Canaanite peoples of the Middle East as a simplified version of Egyptian hieroglyphs. This language, which incorporated a mixture of the earlier hieroglyphic system and later Semitic letters, enabled the average person to write down their thoughts and feelings for the first time. Previous to this, the physical writing of information had been a highly restricted practice, typically the reserve of priests and the well educated. Today, all subsequent alphabets have descended in one way or another from this first phonetic system and are used to communicate the world over.

11. SEWAGE SYSTEM

2500 BCE

The creation of the first sewage system surely has to be one of the most fundamental life-bettering inventions of all time. Starting as simple, below-floor-level cesspits before evolving into brick-lined drains and, in more recent times, full-blown underground networks of tunnels and recycling centres, sewage systems have been an intrinsic part of civilisation since circa 2500 BCE. Excavated homes from the Indus Valley in Pakistan are some of the earliest to reveal the remains of connections to a large sewage drain.



Cruise ship

With the largest cruise ships capable of carrying over 5,400 passengers, today's vessels tend to resemble floating cities more than boats.

10. SOAP

2800 BCE

Soap, in its most fundamental form, first emerged in Babylonia almost 5,000 years ago. This crude soap was a mixture of fat and ashes, which were boiled together in a big cauldron and then stored in clay pots. This emulsifying agent was later refined in Spain during the 19th century into the hard white soaps we are more familiar with today. Originally this new take on soap was made from olive oil and the ashes of the salsola plant.

12. MAGNETIC COMPASS

200 BCE

It was the Ancient Chinese who first discovered the orientating effect of rare ore magnetite and, following this, they put it to use as a crude form of compass in the lodestone. It was more than 1,000 years later before a true navigational compass appeared, again devised in China. The compass was a remarkable milestone in navigation, removing the need for sailors to rely on landmarks and celestial bodies to plot a course and thereby mitigating the uncontrollable factors of overcast weather and darkness. The compass undoubtedly played a huge part in the Golden Age of Exploration during the 16th and 17th centuries.

13. PARCHMENT

150 BCE

While papyrus scrolls and cuneiform tablets predated parchment, its creation was arguably far more important in the grand history of writing, as it paved the way to the development of the first book. Papyrus only came in scroll form and was relatively stiff, while parchment – being made from the scraped skins of animals – was smooth, flexible and more resistant to variable environments and atmospheres. This allowed multiple sheets of parchment to be sewn together into larger manuscripts.

17. ROCKET

904

After the Chinese had invented gunpowder they soon created something called 'fire arrows'. These weapons were standard arrows with a tub of gunpowder strapped to the shaft that exploded on contact. By the early 13th century, fire arrows had evolved into rockets, with individual arrows carried at great speed by attached rocket tubes, very much like modern-day fireworks.

18. SPECTACLES

1286

Today there are many people around the world with some sort of eye deficiency, so it's a good job we have eyeglasses to help correct vision. This wasn't the case before the late 13th century, as prior to the invention of the spectacles in Italy the optical powers of lenses were poorly understood. Even after they were developed, only the richest visually impaired would have been able to afford a pair of specs to help them see.

19. CLOCKS

Late 13th century

While water clocks and, even earlier, sundials had been in use for centuries, it wasn't until the end of the 13th century that weight-powered mechanical clocks began to appear. Who exactly invented the first mechanical clock is lost in time – excuse the pun – but records show that complex escapements and mechanical clocks were becoming commonplace in church towers by the close of the 14th century in Europe. Since then, the accuracy of mechanical clocks has been consistently improved, doubling in accuracy about every 30 or so years on average.

200 BCE

14. CALENDAR

46 BCE

While the Sumerian lunar calendar had been in use since about 2000 BCE, the invention of the Julian calendar – a reform of the earlier Roman calendar – by Julius Caesar in 46 BCE proved to be one of the most resilient and well used of all time. Indeed, it wasn't until 1582 that it was superseded by the Gregorian calendar, which was introduced by Pope Gregory XIII. Today, the Gregorian calendar is internationally the most widely used calendar.

15. GUNPOWDER

800

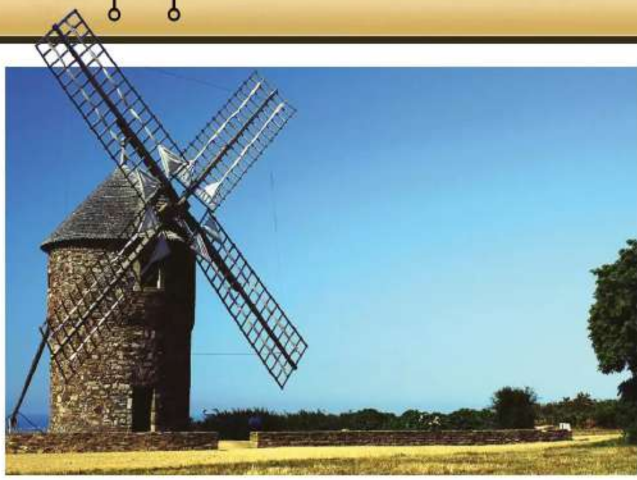
Invented by Chinese alchemists, gunpowder is one of the deadliest-ever human creations. In its original form – a mix of potassium nitrate, charcoal and sulphur – it was used to power a fire lance, a primitive spear launcher made from a bamboo tube and reinforced with metal hoops. Through the Middle Ages its use became ever-more refined for shooting cannons and muskets.

"GUNPOWDER WAS [FIRST] USED TO POWER A FIRE LANCE, A PRIMITIVE SPEAR LAUNCHER"

16. WINDMILL

800

The windmill was invented in eastern Persia during the 9th century. According to surviving documents, these early windmills had between six and 12 sails made up from reed and cloth matting and were used to either grind grain or draw up water – the latter typically as part of an irrigation system. The now-traditional horizontal-axle windmill (pictured) – such as those found in Holland – was invented much later, appearing in Europe during the 18th century. Today windmills have declined in use, though their principles still apply to newer inventions such as wind turbines.



EVOLUTION OF...

23. TELESCOPE

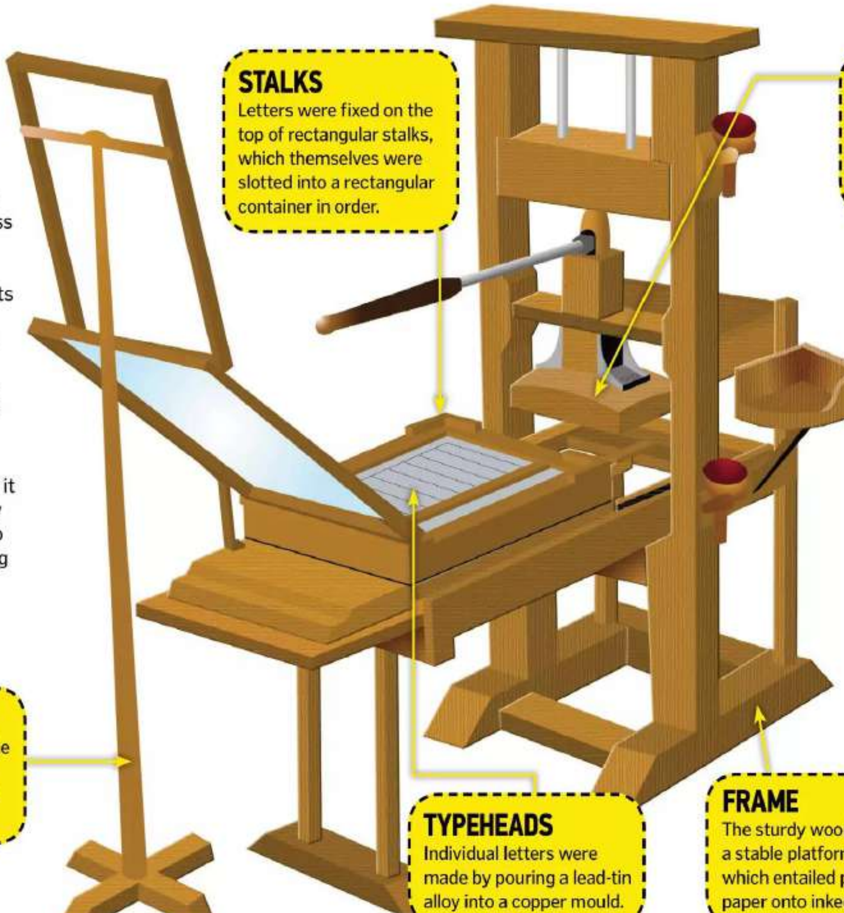
1609

The invention of the telescope is generally now attributed to the German-Dutch lensmaker Hans Lippershey, but many have argued it was not until Galileo Galilei copied his designs and improved upon them in 1609 that the telescope, as we know it today, was born. Galileo's telescope reportedly offered 20x magnification and through it the astronomer discovered four of Jupiter's satellites and that the Sun was covered in spots. Since then, the telescope has evolved massively and today enables us to explore some of the very deepest reaches of space. Check out some of the key points in the telescope's development now...

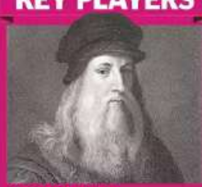
20. PRINTING PRESS

1450

Surely this is one of humankind's most edifying inventions. The printing press – built by Johannes Gutenberg in the mid 15th century – allowed documents and books to be produced quickly and cheaply in bulk, bringing literature to the masses. Indeed, this device wrenched the knowledge of the ages away from a minority of wealthy and learned scholars and placed it in the hands of the everyday person, inspiring many to go on and make world-changing inventions of their own.



KEY PLAYERS



LEONARDO DA VINCI

1452-1519

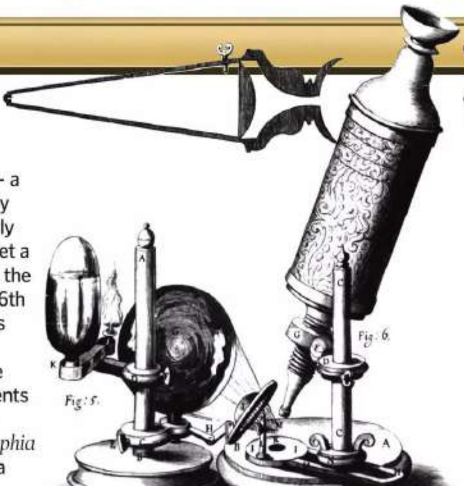
This legendary Italian polymath is one of the greatest-ever inventors due to the massive catalogue of inventions he created in his lifetime. The extensive list includes many objects that are still in use today, such as hydraulic pumps, mortar shells, hang-gliders and machine guns.

1609

21. MICROSCOPE

1590

It wasn't until Zacharias Janssen – a Dutch lensmaker – realised that by inverting the lens structure of early prototype telescopes you could get a high degree of magnification that the microscope was invented in the 16th century. These initial microscopes were simple compound types, combining a magnifying objective lens with an eye lens. Advancements soon followed though and, after Robert Hooke published *Micrographia* in 1655, the microscope became a staple tool for any scientist.



22. FLUSH TOILET

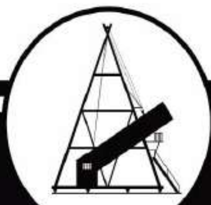
1596

Toilets had been in use for centuries by the end of the 16th century, often with a sewage system. However, these toilets were in reality mere pits/holes, with no moving mechanisms in the waste removal process. That changed in 1596 when writer John Harington installed a flush toilet in his house in Kelston, England. The design used a special valve to let water out of a suspended tank and into the bowl, flushing away the waste.

Lippershey telescope
A simple tube filled with a convex and concave lens, the original Dutch-made telescope offered a rather basic 3x magnification. Nevertheless, it was quickly sold throughout the Netherlands and much of Europe.

Galileo telescope
One of the most important in popularising these instruments, the Galilean telescope was the first to offer large magnifications of 20x and up. After Galileo showed his telescope to the Doge of Venice, it took off all over the continent.

Newtonian telescope
Dissatisfied with flaws in refracting telescopes, Isaac Newton invented the reflecting telescope in 1668, presenting a second refined version to the Royal Society in 1672. Today, the majority of domestic telescopes are of the reflecting type.



Herschel's 40-foot telescope
British astronomer William Herschel built over 400 telescopes, but his largest was a 12-metre (40-foot) focal length reflecting telescope made in 1789. On the first night of using it, he discovered a new moon of Saturn.

Very Large Telescope
One of the most advanced and powerful telescopes that exists on the planet today, the European Southern Observatory's Very Large Telescope (VLT) array, based in Chile, is capable of imaging entire galaxies in phenomenal detail.

26. VACCINATIONS

1796

Dying of smallpox was not a pleasant way to go, with a slow and painful death almost guaranteed. On the other hand, catching cowpox was only a minor inconvenience and, better yet, it prevented you from catching smallpox. English doctor Edward Jenner noticed this link and, after experimenting on some of the local dairy workers, published his results in 1798. He invented a vaccine that later became mandatory, though there were a lot of naysayers before his research was finally recognised.

27. BATTERY

1799

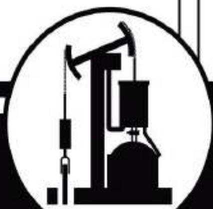
When Italian scientist Alessandro Volta made his voltaic pile in 1799, he started the journey to today's widespread electrochemical batteries. The pile, which was a stack of silver and zinc discs separated by pieces of brine-soaked fabric, was crude, but when its ends were connected via metal wire, it produced a small electric current. In the years following the pile's invention, the battery was improved again and again, and now it is a fundamental source of portable power that many of us just couldn't live without.

EVOLUTION OF...

24. Engine

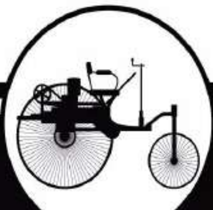
1712

From the 1712 Newcomen steam engine through to Karl Benz's two-stroke petrol engine used in cars and on to today's hi-tech hydrogen varieties, there is no doubt that the engine is one of the most significant inventions ever. Its usefulness has essentially been unrivalled for over 300 years as a motive force and, looking to the future, it seems to have plenty of life left in it. We pick out some of the key developments in its evolution now...



Steam engine

Steam engines date back to the 1st century CE, but it wasn't until Thomas Newcomen's engine in 1712 that they became useful machines.



Petrol engine

Karl Benz's invention of a reliable two-stroke petrol engine marked the end of the steam engine and led to the proliferation of the motor car.

Diesel engine

While the petrol engine was more momentous, Rudolf Diesel's creation of the diesel equivalent was just as useful and more eco-friendly too.

Electric engine

When Camille Jenatzy built an electric car in 1899, his electric engine was openly mocked. The car went on to break the land speed record.

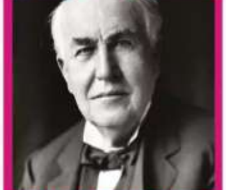
1712

25. ELECTRICITY

1752

Okay, so this isn't an invention but rather a discovery. It is still, however, so momentous that it deserves a mention. While scientists had been fascinated with lightning and electricity for thousands of years – indeed, great philosopher Thales of Miletus undertook numerous experiments into the nature of static electricity in 600 BCE – it wasn't until Benjamin Franklin studied the phenomenon in 1752 that the two were reconciled and its true power realised. Following Franklin's work, electricity was harnessed in increasingly diverse ways, with Michael Faraday using it to lay down the foundations for the electric motor.

KEY PLAYERS



THOMAS EDISON

1847-1931

Probably the greatest American inventor ever, Edison was responsible for the first commercially successful light bulb, the phonograph, the electric vote recorder, the railway turntable and the kinetographic camera (one of the first motion-picture cameras), to name a few.

28. CANNED FOOD

1810

While canned food may get a bad rap today for not being 'fresh', it has been and remains a critical source of nourishment in many parts of the world. Indeed, canned food has many benefits, including acting as a preservative and providing a protective container for transportation. As such, when it was invented in the early 19th century, it radically transformed what the average person ate.

29. PHOTOGRAPHY

1826

For centuries the only way to record a person or place was with paint, which was a time-consuming and expensive process. That all began to change in 1826 when Joseph Nicéphore Niépce – a French inventor from Chalon-sur-Saône – produced the first permanent photographic image by covering a pewter plate with bitumen. Niépce continued to experiment and, after replacing the bitumen with silver, produced one of today's earliest surviving photographs.

30. LIGHT BULB

1835

Many years before Thomas Edison and Joseph Swan introduced their own light bulbs to the world, a Scotsman called James Bowman Lindsay demonstrated a constant electric light at a public meeting in Dundee. Reportedly, Lindsay's light was so powerful and stable - for 1835 at least - that he could read his book from a distance of 0.4 metres (1.5 feet). Lindsay had invented the world's first electric light bulb, however he neither patented the device nor sold it, instead moving on to wireless telegraphy. Regardless, Lindsay's innovation was continuously honed in the following decades and, after Edison married a stable electric generator to this revolutionary light-giving device, the stage was set for its widespread adoption. Today, it's hard to imagine a world without electric light bulbs and they're often voted one of the greatest inventions of all time in polls.

Hydrogen engine
Still in development today, the hydrogen engine could potentially render petrol-based engines obsolete, helping to cut levels of pollution.

31. PLASTIC

1856

In 1856, British scientist Alexander Parkes created the first man-made plastic from cellulose treated with nitric acid. Trademarked as Parkesine, Parkes' invention soon won him a bronze medal at the 1862 Industrial Exhibition in London and, as a result, he decided to ramp up production of the new material. Unfortunately, after beginning mass production of the plastic, a mixture of demand and high costs saw his company fail and, by 1868, Parkesine was no longer made.

PATENT PENDING

While today the patent is best known for the ongoing corporate patent wars between companies like Apple and Samsung, originally it was an incredibly simple thing. When someone made an invention, their labour was protected from theft so they could enjoy any material benefits that derived from it.

The first reference of a patent system dates from 500 BCE, where in the Ancient Greek city of Sybaris "encouragement was held out to all who should discover any new refinement in luxury, the profits arising from which were secured to the inventor by patent for the space of a year". The history of modern patent law, however, is now widely agreed to have started in Italy in 1474, when a Venetian statute decreed that all completed inventions had to be made public to obtain any ownership rights.

From this point on, patent systems evolved throughout the world, allowing civilians to freely create new inventions and advance society. Today, anyone can request a patent for their invention, provided it is original and does not infringe on any previously filed patents.

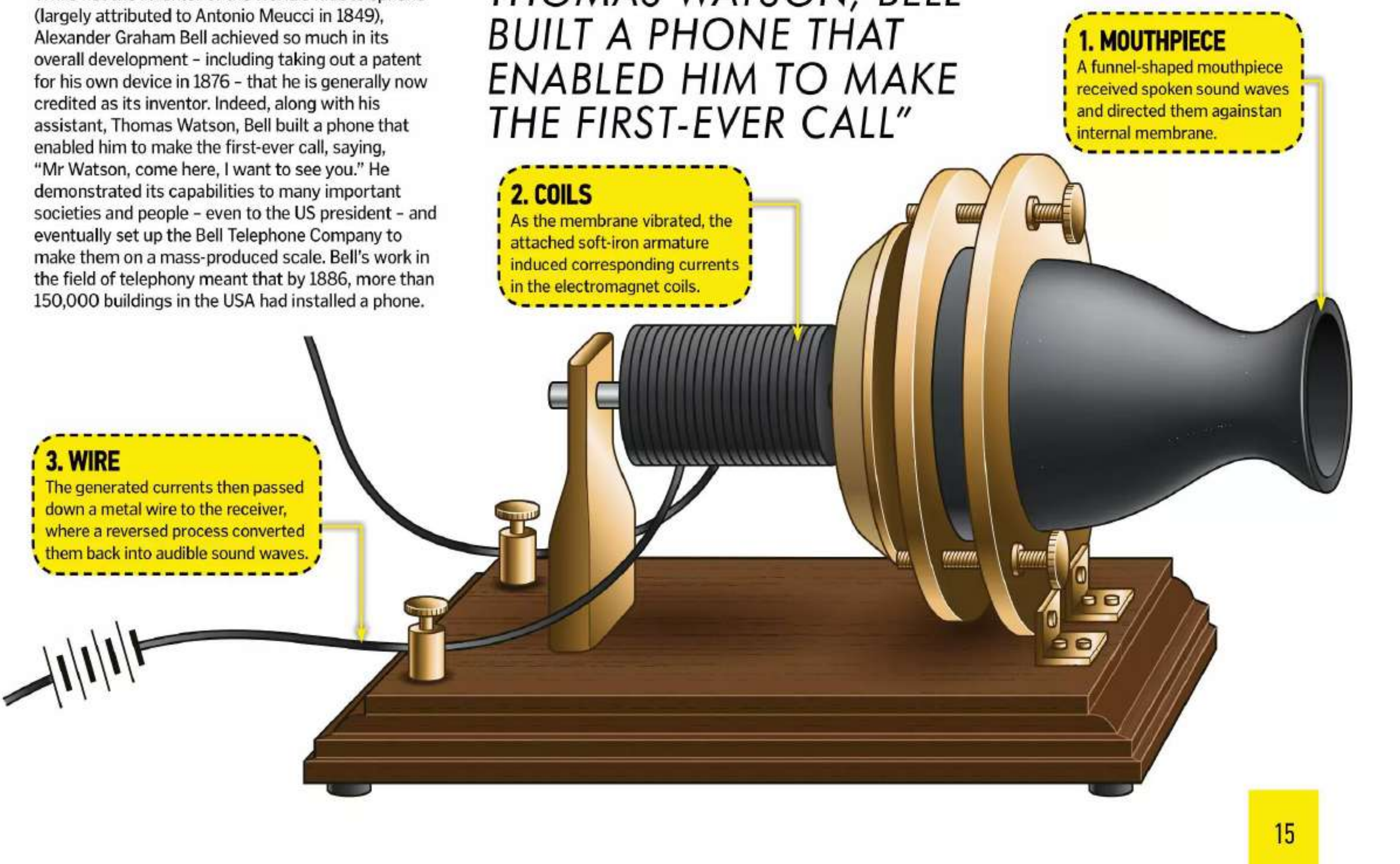
1876

32. TELEPHONE

1876

While not the inventor of the world's first telephone (largely attributed to Antonio Meucci in 1849), Alexander Graham Bell achieved so much in its overall development - including taking out a patent for his own device in 1876 - that he is generally now credited as its inventor. Indeed, along with his assistant, Thomas Watson, Bell built a phone that enabled him to make the first-ever call, saying, "Mr Watson, come here, I want to see you." He demonstrated its capabilities to many important societies and people - even to the US president - and eventually set up the Bell Telephone Company to make them on a mass-produced scale. Bell's work in the field of telephony meant that by 1886, more than 150,000 buildings in the USA had installed a phone.

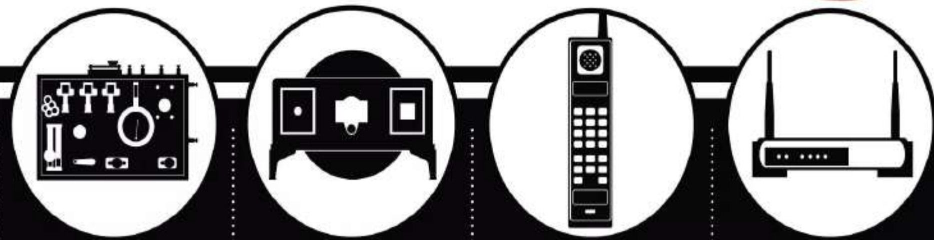
"ALONG WITH HIS ASSISTANT, THOMAS WATSON, BELL BUILT A PHONE THAT ENABLED HIM TO MAKE THE FIRST-EVER CALL"



33. PHONOGRAPH
1877
The first device to be capable of recording and replaying sound, Thomas Edison's 1877 phonograph laid down the foundations for today's music industry, being quickly followed by the gramophone and, later, the turntable. Prior to this, no audible moments could ever be captured or replayed. Today, radios and MP3 players allow us to listen to our favourite tunes all day long.

34. CAR
1882
Taking over from steam- and horse-powered travel at the end of the Industrial Revolution, where would we be today without the car? First made in its current form in 1886 by German engineer Karl Benz, there are now more than 1 billion worldwide, and that number is set to keep growing. Newer designs are looking to solve the problem of pollution by using alternative energy sources, such as hydrogen.

EVOLUTION OF...
36. WIRELESS COMMUNICATIONS
1891
Responsible for eventually giving us the television, mobile phone, radio, radar, satellite navigation and even wireless internet access, Nikola Tesla's work in 1891 creating a wireless communications network was surely one of the most inventive spells of his career. Since Tesla's network, wireless communications have gone from strength to strength, as the following devices show...



Radio
Sir Oliver Lodge sent the first transmission signal in 1894 – a year before Marconi, who was later awarded the wireless telegraph patent.

Television
Scottish inventor John Logie Baird demonstrates the world's first moving image on his 'televisor' device – a mechanical precursor to the TV.

Mobile phone
The first handheld mobile phone is demonstrated by two employees at Motorola. It weighs in at a rather hefty one kilogram (2.2 pounds).

Wi-Fi
While wireless internet existed in academic facilities, it wasn't until 1997 that standards were laid down for its widespread adoption.

1877

35. SKYSCRAPER
1884
The invention of steel-girder skyscrapers enabled architects to move away from the constraints of load-bearing walls and towards steel-framed structures that granted more freedom and creativity. The first of these buildings was architect William Le Baron Jenney's ten-storey Home Insurance Company Building, completed in 1885. As soon as it was built – and proven a success – the technology proliferated rapidly and soon rival architects tried to outdo each other, designing ever taller and more complex buildings.

KEY PLAYERS

BENJAMIN FRANKLIN
1706-1790
Famed for his experiments with electricity, Franklin was also quite an inventor, designing the Franklin stove, bifocal glasses, a flexible urinary catheter, the lightning rod and the glass armonica. He was considered one of the most important figures in the American Enlightenment.

EVOLUTION OF...
39. TELEVISION
1926
Whether or not you think we watch too much TV these days, it's hard to argue that it has not had a beneficial effect since 1926. From allowing national leaders to address the public in times of emergency to educating and entertaining the masses, John Logie Baird's invention has done much good over the last 87 years. Check out some of the telly's milestones now...

ACCIDENTS OF INVENTION

Penicillin

When Scottish scientist Alexander Fleming decided to take a month-long holiday in August 1928 to see his family, he left his London lab in a bit of a mess – including abandoning numerous Petri dishes of staphylococci. Upon his return he noticed that on one of the dishes a mould had grown that had killed any nearby staphylococci. After regrowing the mould in a pure culture, he found that it destroyed a number of disease-causing bacteria. As a result, penicillin – one of the most successful antibiotics to this day – was born.

Coca-Cola

Probably the most commercially successful accident of all time, the soft drink Coca-Cola was not the corporate juggernaut it is today when invented but rather a medicinal cure for headaches... Or so the pharmacist John Pemberton from Atlanta, Georgia, believed when he began selling his secret mixture in 1886 for five cents a pop. 50 years later and Coca-Cola has become a national symbol of America due to its phenomenal success; in fact, in 2011 it was voted the most well-known brand in the world.

Vulcanised rubber

19th-century rubber king Charles Goodyear spent years trying to make a rubber that was easy to manufacture yet resistant to heat and cold. After many failed attempts, one day he just happened to drop a rubber mixture on a hot stove. Believing it ruined, Goodyear retrieved the charred rubber and, when holding it, discovered it was hardened but still flexible. After a little experimentation, he quickly realised that by heating a mixture of rubber and sulphur he could create his desired vulcanised rubber – today used in tyres, shoes and more.

Microwave oven

Percy LeBaron Spencer was not even trying to invent anything when he accidentally conceived of the microwave oven. Working at Raytheon Company during the 1940s, by chance, Spencer noticed one day while walking past a radar tube that a chocolate bar that was in his pocket had melted. After testing the effects with other foods – including popcorn – Spencer realised that magnetrons could be used to cook food, thus devising the concept of the microwave oven.

38. REFRIGERATOR

1922

One of the most useful day-to-day inventions of the 20th century, the refrigerator allows our food to be stored over long periods, reducing the growth of bacteria dramatically. It was invented originally in 1922 when two students at the Royal Institute of Technology in Stockholm, Sweden, created a gas-absorption chilling cabinet. Unlike modern fridges, though, this device did not use an electrically driven compressor to maintain internal temperature, but instead an ingenious system of state-changing gases. After realising its potential, the inventors put the refrigerator on sale. Unfortunately, it never really caught on, leaving the later electric fridge to make the jump to mass-market success.

1928

37. AEROPLANE

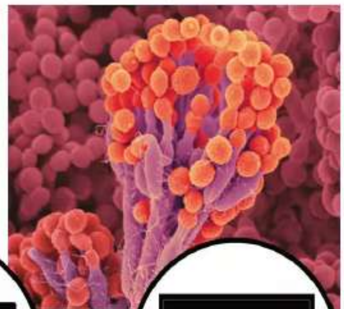
1903

The Wright Brothers' Wright Flyer in 1903 kick-started the age of aviation, with rotor and then jet-powered craft transforming travel in the 20th century. From military fighter jets through to supersized passenger aircraft, air travel means we can reach each other much faster than ever before. To think that within just 73 years we went from the primitive Wright Flyer, which only travelled a distance of 260 metres (852 feet) to the Aérospatiale-BAC Concorde supersonic passenger jet, capable of cruising comfortably at 2,172 kilometres (1,350 miles) per hour for thousands of miles is simply mind-blowing.

40. PENICILLIN

1928

Discovering penicillin might have been a happy accident, but nevertheless Alexander Fleming's find was a pivotal moment in modern medicine, with the bacteria-fighting antibiotic quickly rolled out. Fleming would go on to win a Nobel prize in 1945 for his work. Today, penicillin is available commercially for treating a wide range of infections.



Farnsworth

American inventor Philo Farnsworth makes the first all-electronic TV that is commercially viable, receiving a patent for his device in 1930.

Mass-market

RCA starts the era of mass-produced TVs with the release of the RCA 630TS in 1946. By 1950, the number of TVs has climbed to the millions.

Westinghouse colour

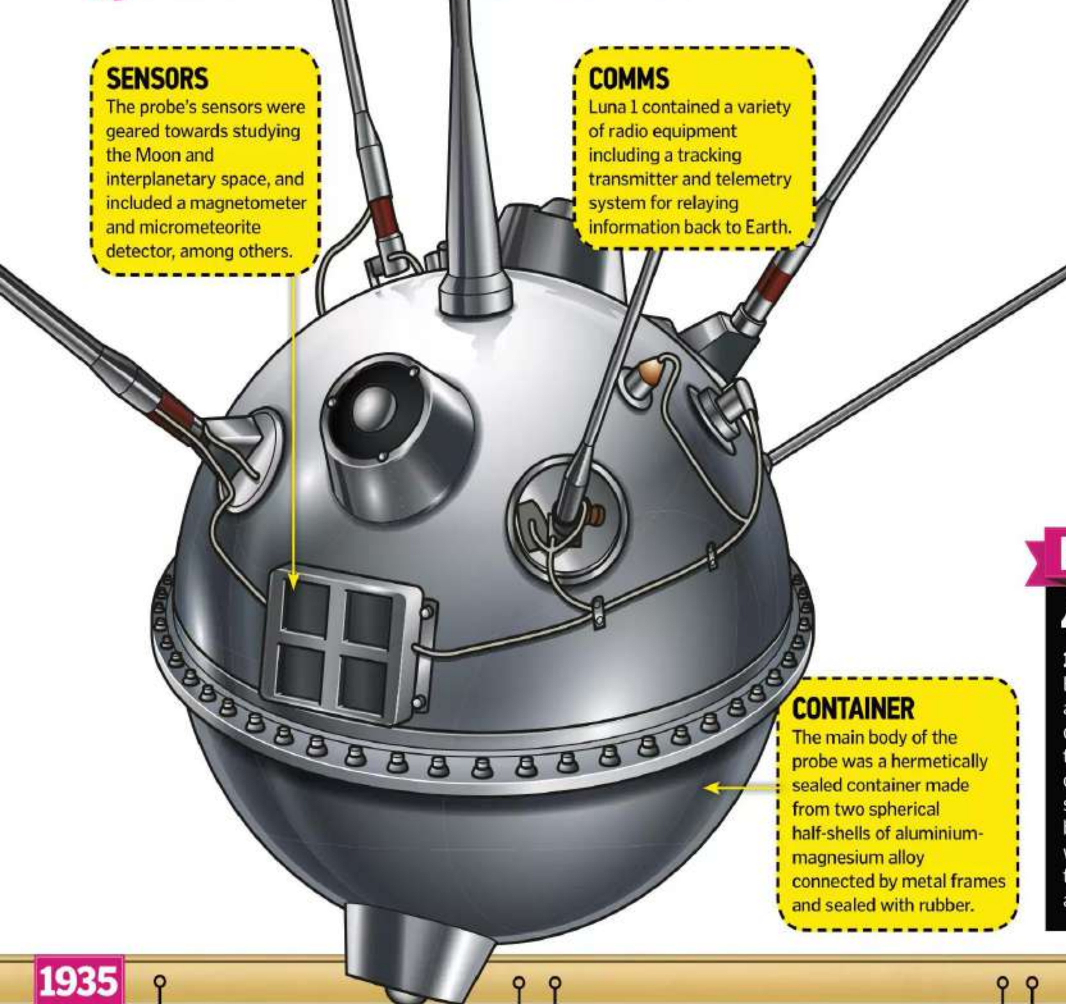
Introducing colour, the Westinghouse H840CK15 goes on sale for $1,295. With only 500 built, it will be 15 years before colour TV goes mainstream.

Casio TV-10

The first LCD TV to be sold commercially is the TV-10, which, while only offering standard low resolutions, kick-starts the flat-panel TV market.

LED backlight

The first LED TV – a flat-panel screen that uses LEDs to illuminate the LCD panel instead of cathode lighting tubes – is produced by Sony.



46. SPACE PROBE
1959

Luna 1 (pictured left) wasn't the first space probe to be built, but it was the first to successfully leave a geocentric orbit – the key criterion for classifying one today. The probe was built as part of the USSR's Luna programme in 1959 and paved the way for a series of other Luna probes that would explore the Moon in unprecedented detail. Today, we have created space probes that are so advanced they can image alien worlds in high definition and travel to the farthest reaches of our Solar System and beyond.

EVOLUTION OF...

49. Personal computer
1973

Be it a desktop, laptop, tablet or smartphone, the average person owns at least one personal computational device, for performing a variety of tasks. Whether it's for writing letters, receiving mail, checking the weather, making phone calls, shopping, playing games, calculating sums or booking a holiday, computers can handle it – and a whole lot more. Indeed, the empowering qualities of the PC are massive and it is easy to see why many argue it's the most important device on Earth.

1935

41. RADAR
1935

It's funny to think that the radar, one of today's most useful inventions, was born out of a British-funded 'death ray' project during the run-up to WWII. But that is exactly what the British government asked Scottish scientist Robert Watson-Watt to build: a machine to 'destroy personnel'. Watson-Watt realised the death ray was impossible to build, but did suggest that radio waves could be used to monitor distant objects.

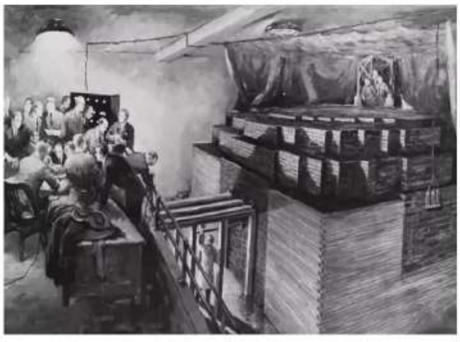
"THE DEATH RAY WAS IMPOSSIBLE, BUT RADIO WAVES COULD MONITOR DISTANT OBJECTS"

43. MICROWAVE OVEN
1947

The microwave oven was created by chance, but despite its serendipitous origins, the first commercial microwave was sold in 1947, with the Raytheon Company releasing its Radarange unit. The Radarange was 1.8 metres (six feet) tall, weighed 340 kilograms (750 pounds) and cost $5,000 – over £33,800 ($51,000) by modern standards! Today, the microwave is a staple feature in most kitchens as a speedy means to cook our food.

42. NUCLEAR REACTOR
1942

The world's first nuclear reactor was the Chicago Pile-1 (pictured), which was constructed as part of the USA's Manhattan Project in WWII. Built under the western stands of Stagg Field at the University of Chicago, the reactor was fairly crude, comprising a pile of uranium pellets and graphite blocks. Regardless of its rustic build, the reactor initiated the first self-sustaining nuclear chain reaction on 2 December 1942 and kick-started the age of nuclear power.



45. CREDIT CARD
1958

Almost nobody goes anywhere today without some form of debit or credit card, but not so long ago all we had was physical currency. However, in 1958 the Bank of America launched its BankAmericard credit card in Fresno, California. Despite the credit card system being abused by fraudsters in its first year, the BankAmericard was eventually a success and, in 1976, changed its name to Visa. Today, Visa cards are one of the most widely used payment cards on the planet.

44. MEDICAL IMAGING
1953

Medical imaging techniques such as ultrasonography – invented in 1953 at the University Hospital in Lund, Sweden – have revolutionised the field of medicine, granting doctors an unprecedented window into their patients' bodies. Today, ultrasound scans use probes with acoustic transducers to transmit pulses into the body to check on babies in the womb and more.

47. INTERNET
1960s

Another invention to which no firm date nor name can be ascribed, the internet nonetheless remains an absolute necessity for a top inventions list. With origins buried in US military facilities during the 1960s as a way to deliver fault-tolerant communication between individual computer networks, the internet soon grew in scale, with the development of increasingly large and complex networks. By the early 1980s, an identifiable backbone of the internet had emerged with its potential being realised both commercially and academically. As a result, companies and institutions started linking their own networks and – along with the birth of the World Wide Web – a new era of online communication, business and entertainment had dawned.

KEY PLAYERS

TIM BERNERS-LEE
1955 – present

As the main brain behind the World Wide Web, Berners-Lee revolutionised communications. While the internet existed pre-1989, it was only used by a select few; the World Wide Web brought it to the masses.

48. SATELLITE
1962

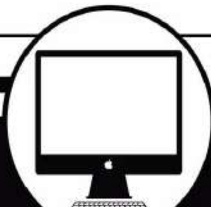
Military and governmental satellites had existed for over half a decade when the Telstar satellite was launched into space on top of a Thor-Delta rocket on 10 July 1962. But that didn't stop it from becoming one of the most important satellites of all time. This was because the Telstar was the first commercially funded initiative to develop satellite communications over Europe – a technological advance that would lead on to today's widespread satellite-reliant communications and entertainment. Indeed, Telstar would go on to successfully transmit the world's first transatlantic television pictures, telephone calls and fax images. Telstar 1 is still in orbit around Earth but is no longer functional.

Xerox PARC
This early personal computer sets the benchmark for their design, incorporating a monitor, keyboard, mouse and graphical user interface (GUI).

Commodore PET 2001
One of the first mass-market PCs, the PET 2001 featured a 1MHz CPU and up to 96KB of memory. It came in a one-piece form-factor, unlike the PARC.

IBM PC 5150
Tech giant IBM's first mass-produced PC sold fantastically well and went on to become a business industry standard. The IBM 5150 had a 4.77MHz CPU.

Power Mac 9500
One of the first of a new wave of hi-spec PCs, the Mac 9500 helped popularise the separate desktop tower case and now-widespread PCI standard connector.



iMac
The iMac helped push the now popular all-in-one unibody design standard, with high-resolution LED screens and super-fast, multi-CPU PCs now the norm.

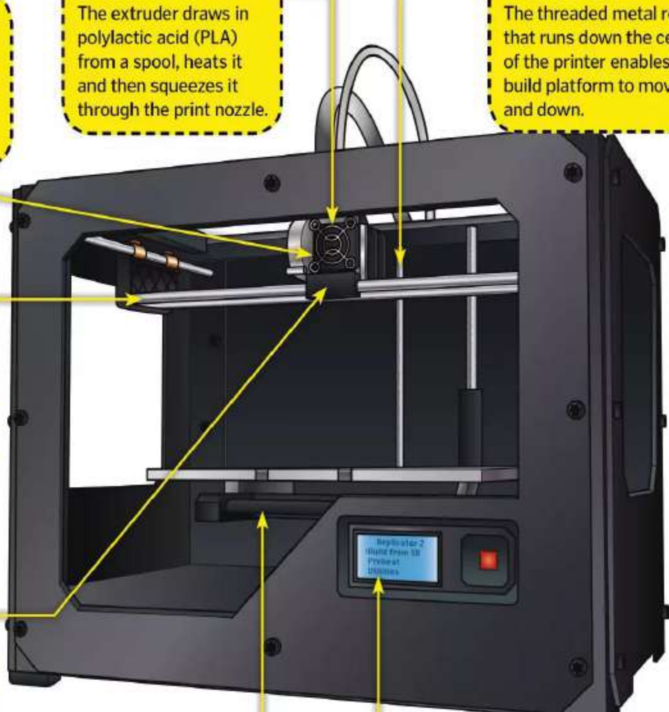
1984

COOLING FAN
An active cooling fan blows on the liquefied PLA as it leaves the nozzle so that it solidifies quickly.

EXTRUDER
The extruder draws in polylactic acid (PLA) from a spool, heats it and then squeezes it through the print nozzle.

Z-AXIS ROD
The threaded metal rod that runs down the centre of the printer enables the build platform to move up and down.

GANTRY
The extruder is secured to a gantry in the top of the printer. The extruder runs on the gantry to allow for each layer's precise positioning.



PRINT NOZZLE
The opening on the end of the extruder from which the heated PLA filament emerges to be deposited onto the build plate.

BUILD PLATFORM
The support for the build plate, where the PLA is deposited. The build plate can be level adjusted to suit a range of printing projects.

CONTROLLER
Instruction sets for an object's cross-sectional layers are fed through the printer's motherboard and into the extruder controller.

50. 3D PRINTER
1984

And so we come to the last of our 50 inventions and, in some respects, we have come full circle, as we end with an invention that is arguably the closest thing we currently have to a machine that can create more machines! And that is the 3D printer, a device born in the mid 1980s that – fed with CAD designs – can build objects, sculptures, gears, component parts, organs, artificial limbs, toys and much more through an ingenious layering of liquid plastics. The complexity of some of the things modern 3D printers are capable of making is truly astounding and, with work already underway to upscale both their commercial availability and their potential applications – such as a project to make a printer capable of printing entire houses – this particular invention has a very bright future ahead of it.

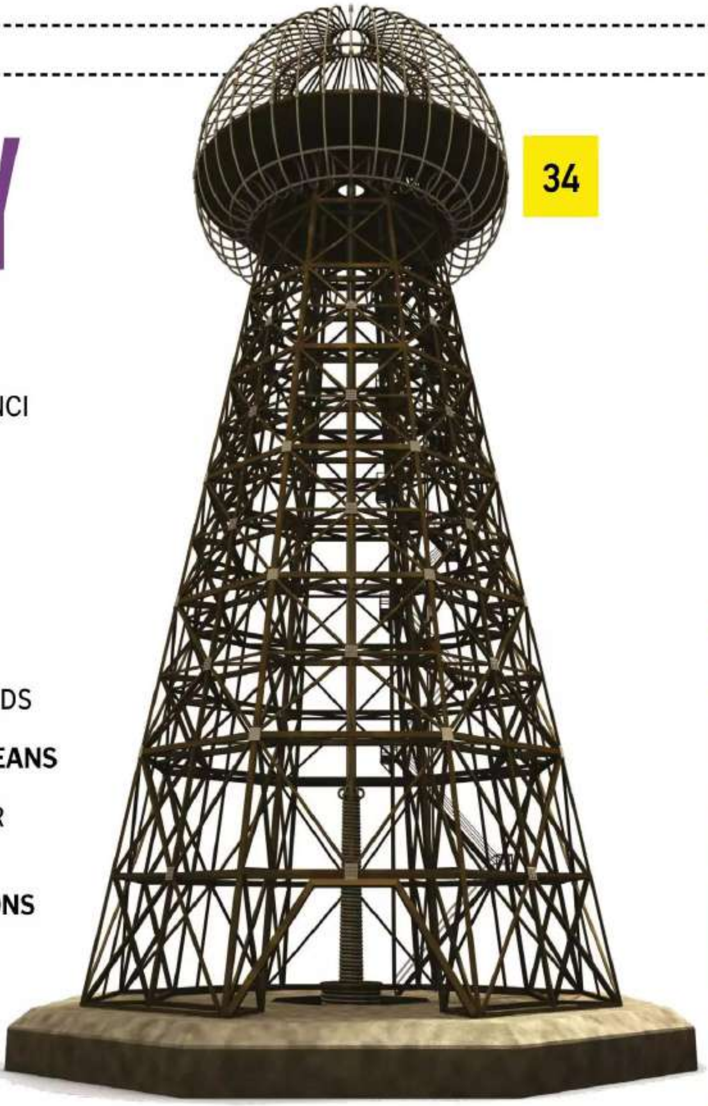
READERS' FANTASY POLL

Which of these inventions do you wish existed?

For fun, we picked five fantasy inventions and asked which you'd like to see. Here are the results.

Rocket boots	9%
Hover car	17%
Robot butler	8%
Teleporter	65%
Everlasting gobstoppers	1%

HISTORY



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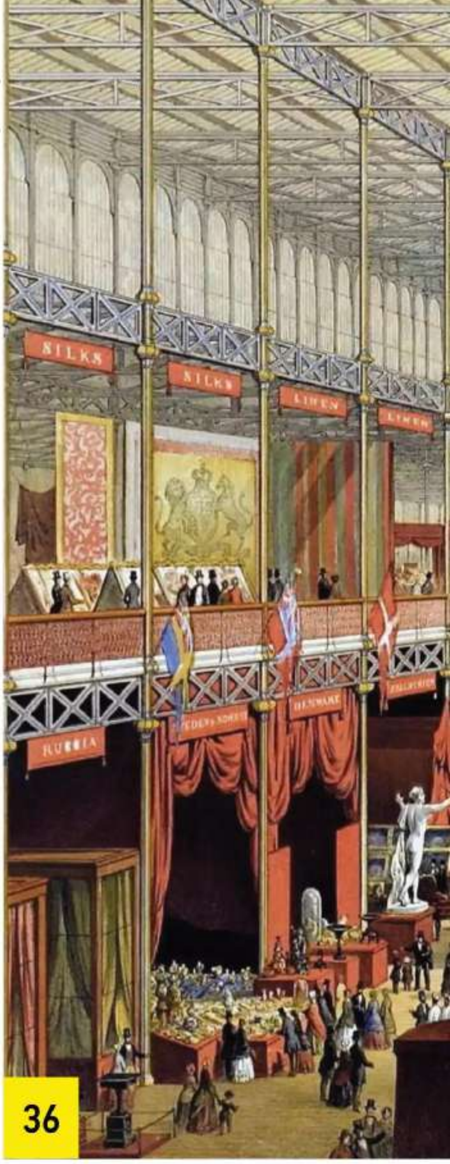

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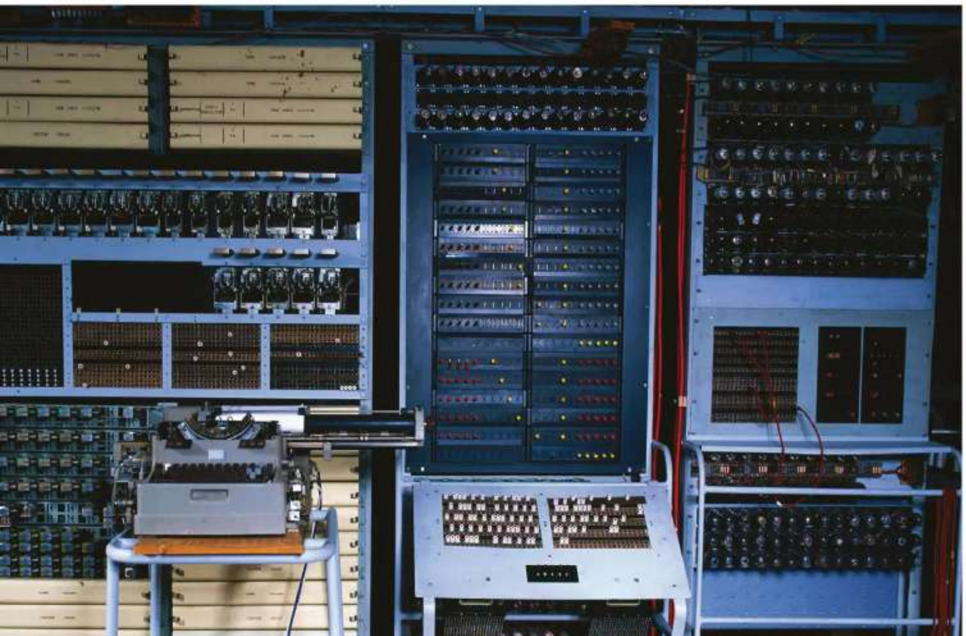

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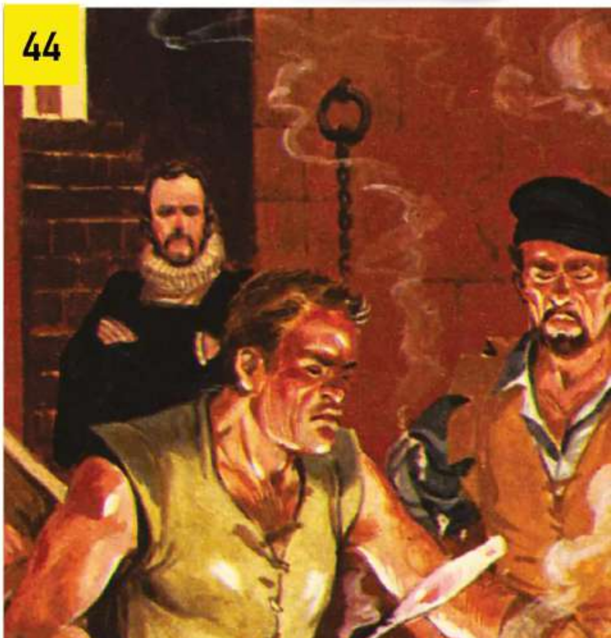

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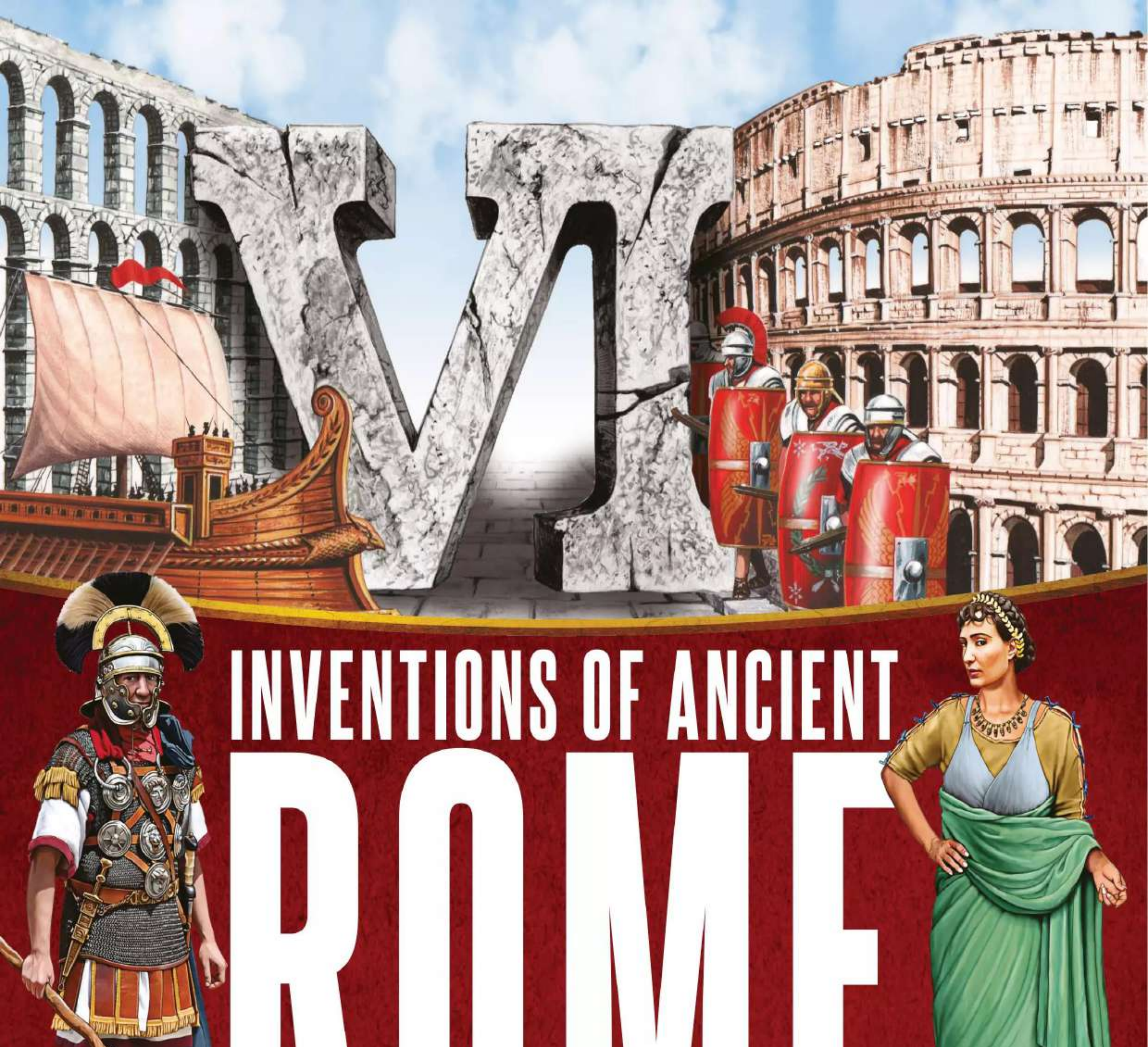


INVENTIONS OF ANCIENT ROME

HOW THE ROMANS CHANGED THE WORLD YOU LIVE IN

Perhaps the greatest of all the ancient civilisations, Ancient Rome represented the age of classical antiquity and helped create the world we live in today. The massive engineering projects that were undertaken and the advances in medicine and society ensure Roman influence can still be felt now. For example, concrete and cement were first popularised in Ancient Rome, as was a type of central heating known as a hypocaust.

One of the most remarkable traits of all, though, was the ability for the Romans to work all their schemes and inventions into fully functioning cities within an extensive empire. Rome itself was a bustling metropolis that no other civilisation matched in prosperity and size for centuries afterward. Nowhere else in the ancient world had grand shopping centres like Trajan's Market, specialised landfill sites such as Monte Testaccio or extensive sewer networks like the Cloaca Maxima. They were also famously proficient at town planning and building large structures.

Home life was revolutionised under the Romans. Also, as is well known, the army was an all-conquering juggernaut that took the old world by storm. To commemorate their affect on modern society and technology, it's time to discover how innovative and groundbreaking this ancient civilisation really was.

1 ENGINEERING IN ROMAN HOME LIFE

THE TECHNOLOGY INSIDE A ROMAN HOUSE

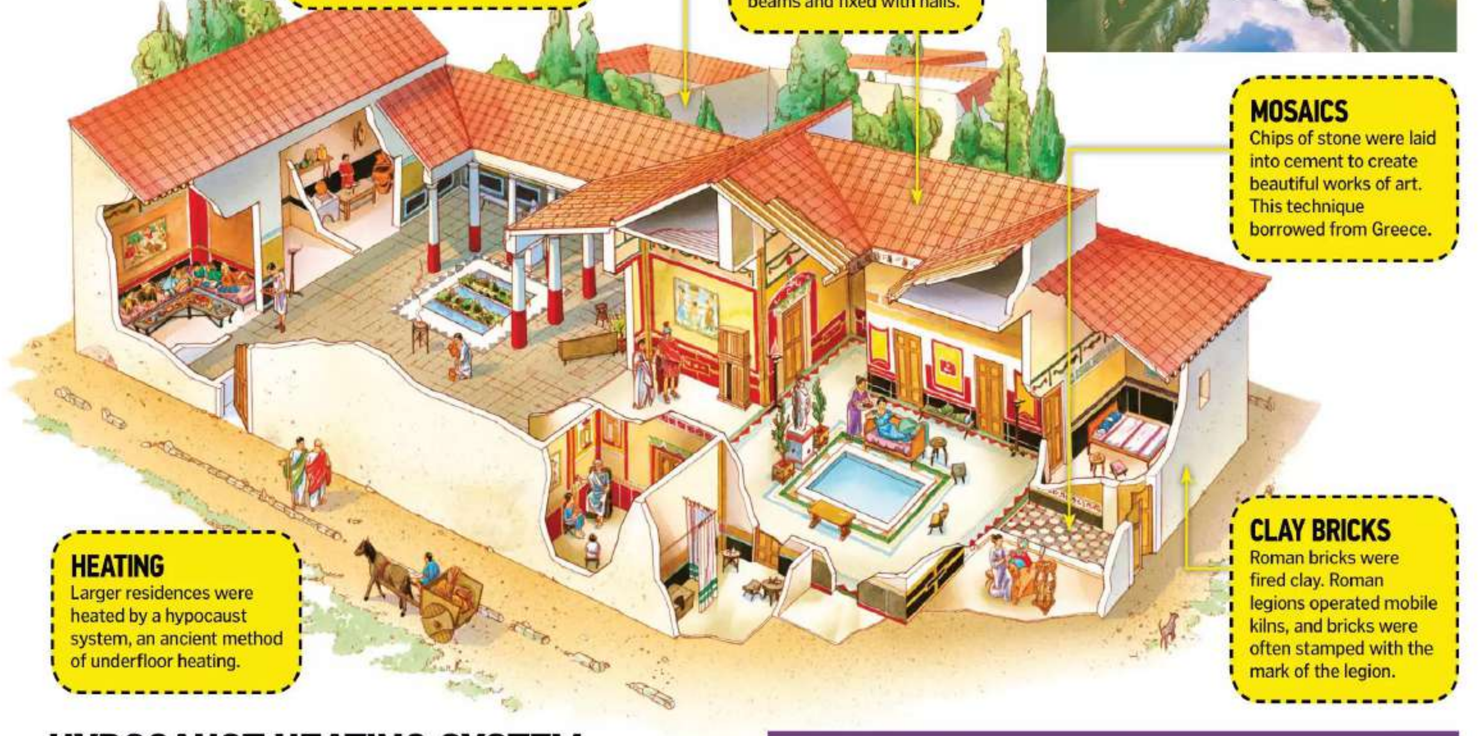
The citizens of Rome had to be properly housed to ensure that the vast urban sprawl could operate as an organised society. Prior to the Romans, impressive structures had been built by the Egyptians and the Greeks, but never on the scale of the Romans.

Roman building techniques owed a lot to Greek and Etruscan influences. Houses were one or two storeys high and included lots of different sections. Ideally adapted to the Mediterranean heat, the typical house often had no windows, instead fitted with an atrium to act as an open-air courtyard in the middle of the building. Life in a house was boosted by a fully functioning public welfare system that provided grain to 300,000 of Rome's families every year. If you wanted some retail therapy, Trajan's Market had over 100 shops selling a variety of goods.

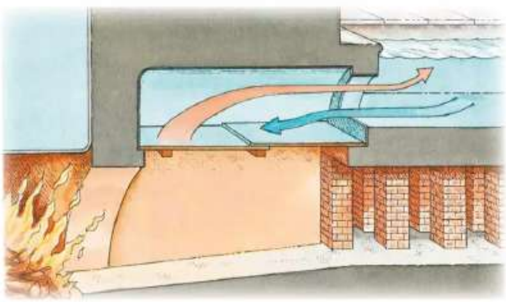
Not every citizen was lucky or rich enough to own a house. Lower classes were put into one of Rome's many insulae apartment buildings, and there are believed to have been over 40,000 of these in the city. In fact, these apartments outnumbered family houses by 20 to one!

THE ROMAN RESIDENCE

MORE THAN JUST A ROOF ABOVE YOUR HEAD, THE ROMAN HOUSE WAS QUITE COMPLEX



HYPOCAUST HEATING SYSTEM



CONVECTION CURRENTS

Underneath a raised floor, vents allowed heated air to travel freely and used convection currents to heat the tiles above. The warm air came from a wood-burning furnace elsewhere in the building.

RUNNING THE HYPOCAUST

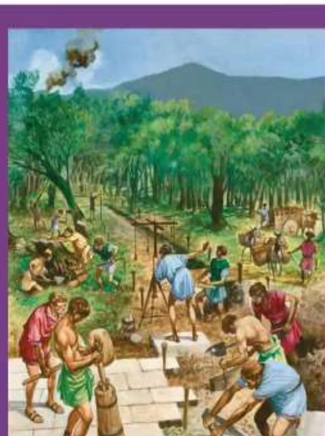
Slaves kept the system running by keeping the flame alight. It is still unknown how well the convection currents worked, and whether some rooms got too hot because of how the system worked.

DISADVANTAGES

The hypocaust was reserved only for the wealthiest villas and large bathhouses. Also, the burning of wood produced toxic carbon monoxide fumes.

2 ROMAN ROADS

Roman roads interlinked cities and towns, allowing rapid military and administrative communications. Construction began with a trench, which was filled with a base of stones and rocks. These were packed together tightly, usually with cement, to create a firm foundation for armies to march on and chariots to ride across. Large paving stones were used on the surface. These were placed and fitted by hand along with channels on the side of the road that allowed water to run off into surrounding fields. In the UK, roads such as the A1 and A5 owe their origins to the Roman conquest of Britain.



3 AQUEDUCT ENGINEERING

HOW THE ROMANS BUILT THEIR IMMENSE WATER-MANAGEMENT NETWORK

Aqueducts weren't invented by Romans but were popularised by them. These structures were the life stream of a city. 1,300 drinking fountains and 144 public toilets were located in Rome and they were all fed by the complex system of aqueducts, which brought in fresh drinking water from rural areas. The system was accompanied by an elaborate network of sewers.

Rome's main sewer was known as Cloaca Maxima, and it carried dirty water out of the city and into the River Tiber. The first-ever aqueduct was the Aqua Appia, built in 312 BCE. It helped relieve the demand for water in a rapidly growing Rome. Where possible, the majority of an aqueduct was built underground to protect it from enemies. The iconic raised arches were only required when the structures neared a city or needed to cross a ravine.

The basic yet effective tools used in construction were the dioptra (measured angles) and chorobates (measured horizontal planes). These were handled by skilled army engineers who designed a gravity based system with dropshafts and chutes to help the water flow. This demonstrated excellent structural engineering and water management expertise, and they were built so well that some are still operational to this day.

1. Building materials
Aqueducts were primarily constructed out of limestone that was mined from neighbouring quarries. These slabs of rock were bound together by Roman concrete and cement, which was made out of durable and waterproof volcanic sand called pozzolana.

2. Planning
The building of aqueducts was often financed by the emperors themselves, so meticulous planning was put into the operation. The land needed to be surveyed by engineers to make sure it was fit for construction.

3. Construction techniques
The reinforced Roman concrete arch was an essential part of the aqueduct as it could hold the pressure and weight of the water after the wooden construction supports had been removed. Pulleys, wedges and screws were used as lifting apparatus.

4. Design and uses
The water was carried a great distance from spring to urban area and was then held in cisterns in the city and onto a network of pipes to each individual building. Aqueducts also aided a town's sewer system and protected against fires.

FLOWING FAR

Many claim that aqueducts were one of the best Roman developments. Frequent throughout the Roman world, their effective and modern system was lost after the fall of the empire and never recovered until much later.

A lot of these structures were actually underground, but they are most fondly remembered for their overground segments with their iconic vaulted arches that were essential in their construction. As techniques improved, aqueducts were also used to supply out-of-town factories and mines with water.

The longest aqueduct in Rome was the Aqua Marcia, which spanned 91 kilometres (57 miles) from source to city, but even longer systems were built across the empire.

4 ROMAN NEWSPAPERS

All citizens in Rome were kept up to date with two daily newspapers. The Acta Senatus made sure the public was up to speed with what was going on in the Senate, while the Acta Diurna was a daily gazette focused on Roman news and weather. Both publications were handwritten so their circulation wasn't exceedingly high, but the Acta Diurna lasted two centuries of service. The Senatus wasn't so lucky as several emperors forbade its publication and preferred to keep Senate minutes private. They were also pioneers of the postal service. The Cursus Publicus was a state-run courier system that delivered messages throughout the Roman Empire.

5 BUILDINGS

THE BIGGEST CITIES WERE HOME TO THE BIGGEST BUILDINGS

In its prime, Rome was one of the, if not the most, technologically advanced cities in the world. Containing huge, expansive buildings, revolutionary architecture and a housed, fed and watered population within its walls, the vast empire's capital in Rome was well ahead of its time.

The Colosseum became the cultural centre of Rome after its construction in 80 CE, but the capital also contained one of the largest sports stadiums of all time, the Circus Maximus, as well as other examples of stunning engineering, such as the Pantheon, the Arch of Septimius Severus and the Theatre of Pompey.

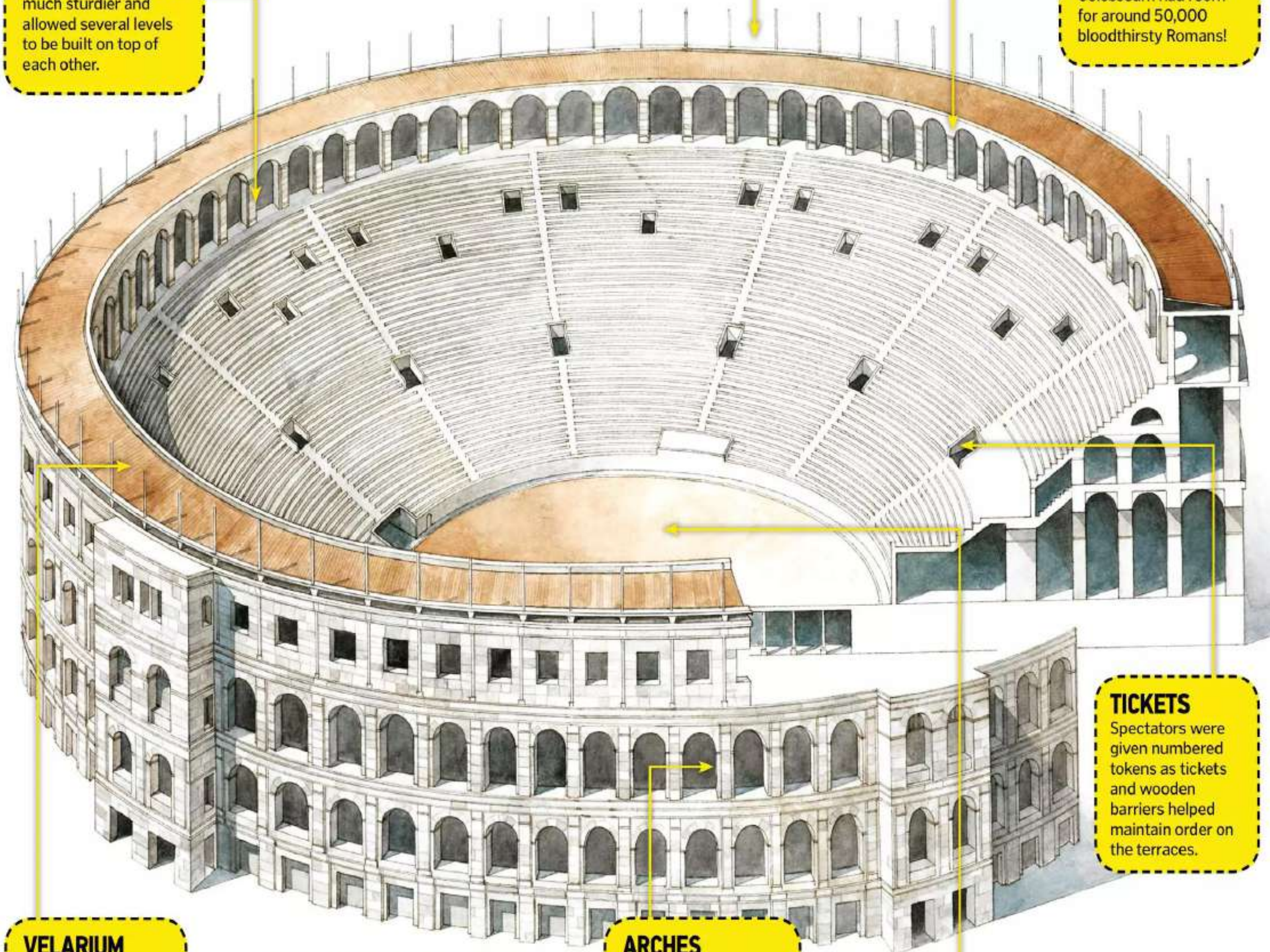
THE COLOSSEUM

HOW THE CENTREPIECE OF THE EMPIRE WAS BUILT

ALL IN A NAME
The name 'Colosseum' comes from the word 'colossus', which was the name of giant statues erected in the city by Emperor Nero.

CONCRETE AND CEMENT
Pozzolanic ash-based cement made buildings much sturdier and allowed several levels to be built on top of each other.

DIMENSIONS
48m (157ft) high and 189x156m (620x512ft) in length and width, the Colosseum had room for around 50,000 bloodthirsty Romans!



TICKETS
Spectators were given numbered tokens as tickets and wooden barriers helped maintain order on the terraces.

VELARIUM
All the spectators in the Colosseum were protected from the hot Mediterranean sun by an awning called the velarium.

CONSTRUCTION
The Colosseum's outer wall was made from 100,000m^3 (3.53mn ft^3) of limestone held together by 300 tons of iron clamps.

ARCHES
80 concrete arches meant the Colosseum had an extremely durable design, which has allowed it to stand for nearly 2,000 years.

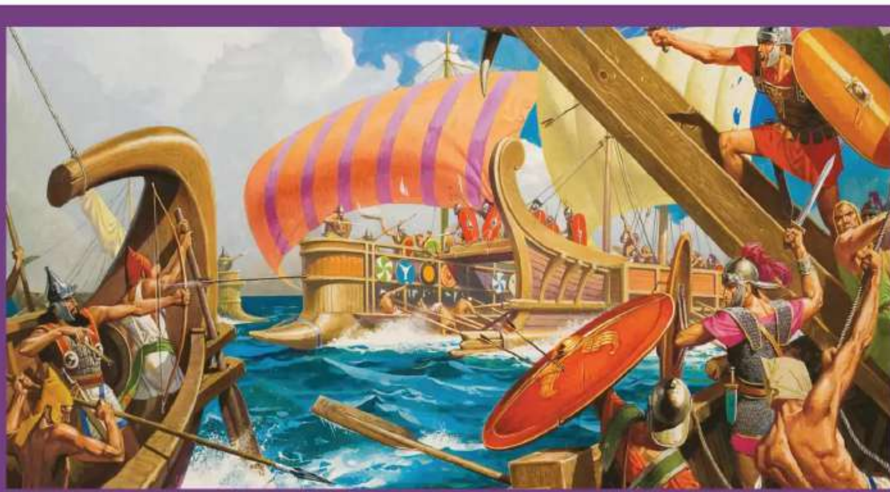
UNDERGROUND LABYRINTH
Underneath the Colosseum was a system of tunnels that elevated cages into the arena using a slave-run pulley system.

6 MILITARY

INGENIOUS CONQUERORS

On both land and sea, the Romans dominated warfare for centuries, invading large portions of Europe and making significant inroads into Africa and Asia Minor. The Romans outwitted their opponents using expert battle tactics like the testudo, or tortoise, shield formation, and they also had perfectly engineered weapons and armour.

Soldiers were divided into legions of about 4,500 men, and each legion served in different territories and swore an oath of loyalty to the centurions. One of the main reasons why the Romans consistently beat their enemies (and what links them to today's military) is the fact that the army was a professional conscripted force. A full-time operation, a soldier was one of the highest-paid and most-respected occupations in the empire.



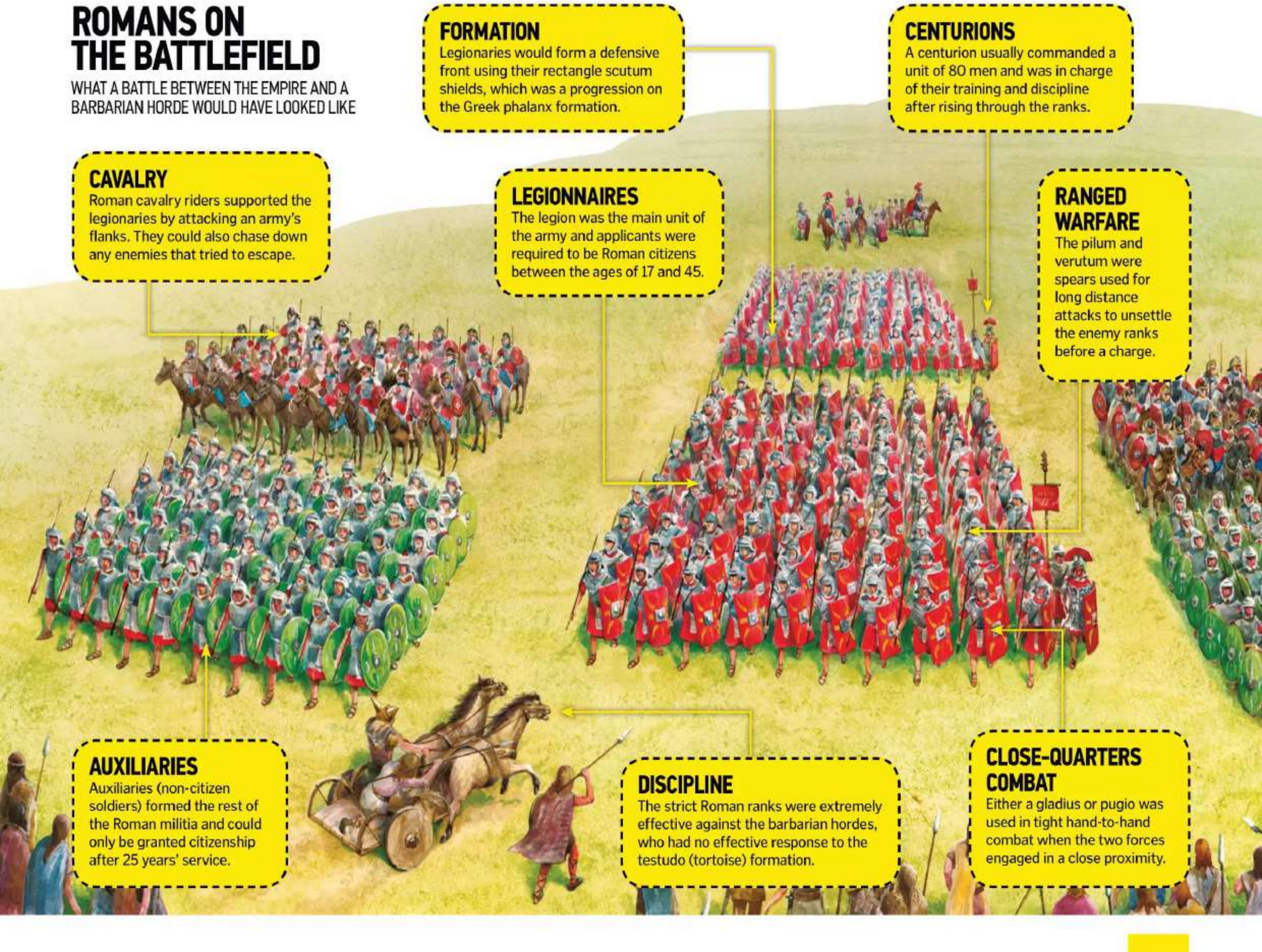
THE WAR AT SEA

On the high seas of the Mediterranean, the Romans enjoyed even more dominance than on land. Using triremes and galleys propelled by teams of over 100 men, ships attacked either by ramming the opposition or boarding their ships. Owing a lot of their strategies to reverse-engineering methods learnt from the Greeks and Carthaginians, maritime superiority was essential to win Roman victories in the Punic Wars and Egypt campaigns.

The senior arm of the Roman navy was known as the Classis Misenensis, and except for internal civil wars, it achieved total marine dominance for Rome after the Punic Wars.

ROMANS ON THE BATTLEFIELD

WHAT A BATTLE BETWEEN THE EMPIRE AND A BARBARIAN HORDE WOULD HAVE LOOKED LIKE



THE GENIUS OF DA VINCI

SO MUCH MORE THAN JUST A PAINTER, THE FAMOUS RENAISSANCE POLYMATH INVENTED A PLETHORA OF MARVELLOUS MACHINES

Leonardo da Vinci was the epitome of a Renaissance man. While renowned as an artist, he was also a brilliant scientist and engineer. Beyond his famous paintings, such as *The Last Supper* and the *Mona Lisa*, da Vinci's journals reveal a range of observations and studies, from anatomy to astronomy, and palaeontology to philosophy.

The Renaissance was a period of cultural revival, which began on the Italian Peninsula in the 14th century as the Middle Ages came to an end. Da Vinci was born in 1452 into a world that had become more accommodating to new ideas. A year after his birth, the capital of the Byzantine Empire, Constantinople (now Istanbul), fell to the Ottomans. As talented scientists and artists escaped the war-torn Bosporus to seek safety in Italian city-states, the country became a hub of learning. One city the fleeing scholars settled in was Florence.

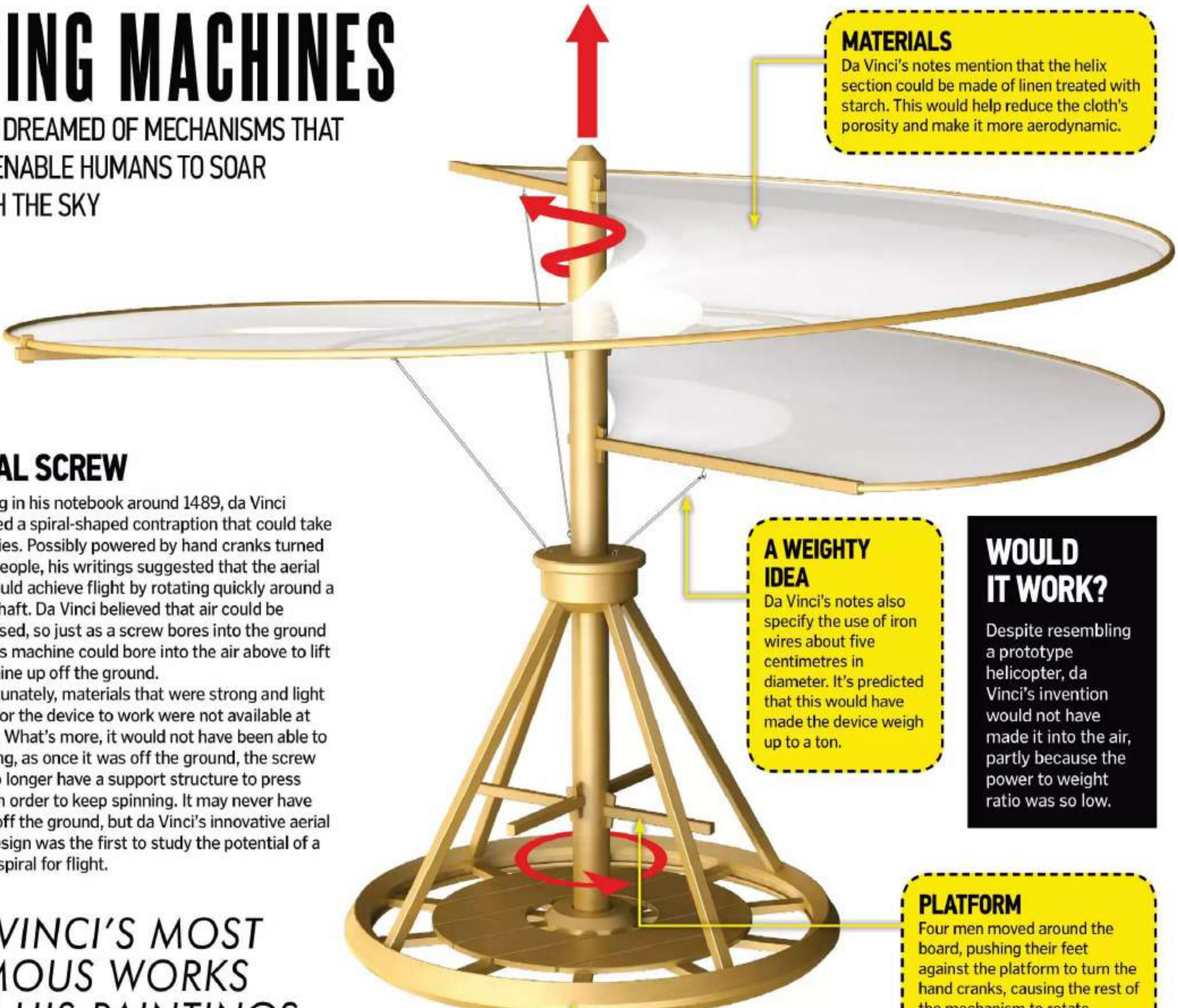
Here they were encouraged to study and invent by the ruling Medici family, who happily bankrolled learning centres all over the city. An intellectual and cultural revolution began; new technological and scientific ideas were spread with help from the recent invention of the printing press, as Europe began to catch up with academics from the Islamic world. It is likely that the inventions and creations of other Renaissance men like Mariano di Jacopo (also known as Taccola) and Filippo Brunelleschi influenced da Vinci, who revelled in the idea of Renaissance Humanism, a notion that encouraged learning and built on critical thinking methods that had stagnated in the Medieval period.

Da Vinci's most famous works are his paintings, but he was also a creative and talented engineer and inventor. The rediscovery of his codices in the 19th century revealed plans for an array of contraptions, from battlefield tanks to flying machines. His ideas were influenced by antiquity and observations of the natural world. For example, a tortoise shell was the inspiration for his armoured car, while observations of birds, bats, flying fish and even plants contributed to the designs of his various flying machines.

His ideas were ambitious, but they were grounded in logical calculations based on scientific theories and mathematical principles. For the most part, these designs were only held back by the technological restrictions of the time. While many of da Vinci's manuscripts were inadvertently destroyed after his death, over 5,000 pages of his journals still exist today, providing us with a glimpse into the mind of a man ahead of his time. Da Vinci may have died nearly 500 years ago, but the legacy of his creativity and innovation lives on.

FLYING MACHINES

DA VINCI DREAMED OF MECHANISMS THAT WOULD ENABLE HUMANS TO SOAR THROUGH THE SKY



AERIAL SCREW

Scribbling in his notebook around 1489, da Vinci envisioned a spiral-shaped contraption that could take to the skies. Possibly powered by hand cranks turned by four people, his writings suggested that the aerial screw could achieve flight by rotating quickly around a central shaft. Da Vinci believed that air could be compressed, so just as a screw bores into the ground below, his machine could bore into the air above to lift his machine up off the ground.

Unfortunately, materials that were strong and light enough for the device to work were not available at the time. What's more, it would not have been able to fly for long, as once it was off the ground, the screw would no longer have a support structure to press against in order to keep spinning. It may never have made it off the ground, but da Vinci's innovative aerial screw design was the first to study the potential of a rotating spiral for flight.

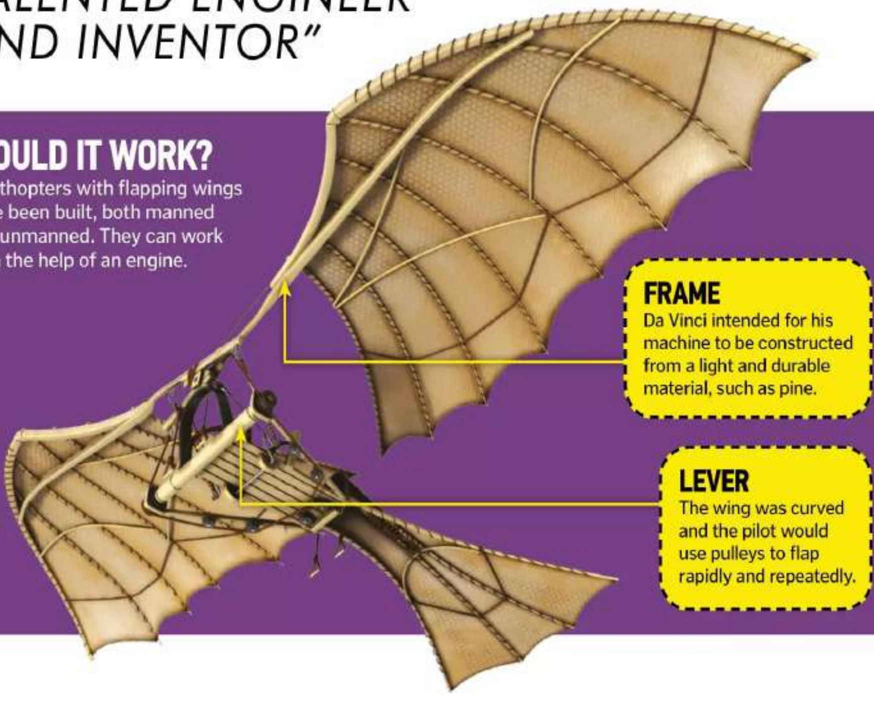
WOULD IT WORK?

Despite resembling a prototype helicopter, da Vinci's invention would not have made it into the air, partly because the power to weight ratio was so low.

"DA VINCI'S MOST FAMOUS WORKS ARE HIS PAINTINGS, BUT HE WAS ALSO A CREATIVE AND TALENTED ENGINEER AND INVENTOR"

WOULD IT WORK?

Ornithopters with flapping wings have been built, both manned and unmanned. They can work with the help of an engine.



THE ORNITHOPTER

Da Vinci observed birds and other animals in flight, and he became obsessed with the idea of a contraption that would allow humans to do the same. One of his ideas was an ornithopter, which was powered by flapping mechanical wings.

Da Vinci wrote over 35,000 words and drew 500 sketches on flying machines. He understood that birds relied on both lift and propulsion to maintain flight, and that they balanced themselves with both wings and tail. He hinted at the idea of gravity and understood that flying machines had to be as lightweight as possible. His sketches demonstrate knowledge of aerodynamics, showing how airflow could be streamlined and how aircraft produce drag. The only drawback was the human body, which is simply not built to achieve flight on its own, nor muscular enough to power a mechanical engine for flight.

WAR MACHINES

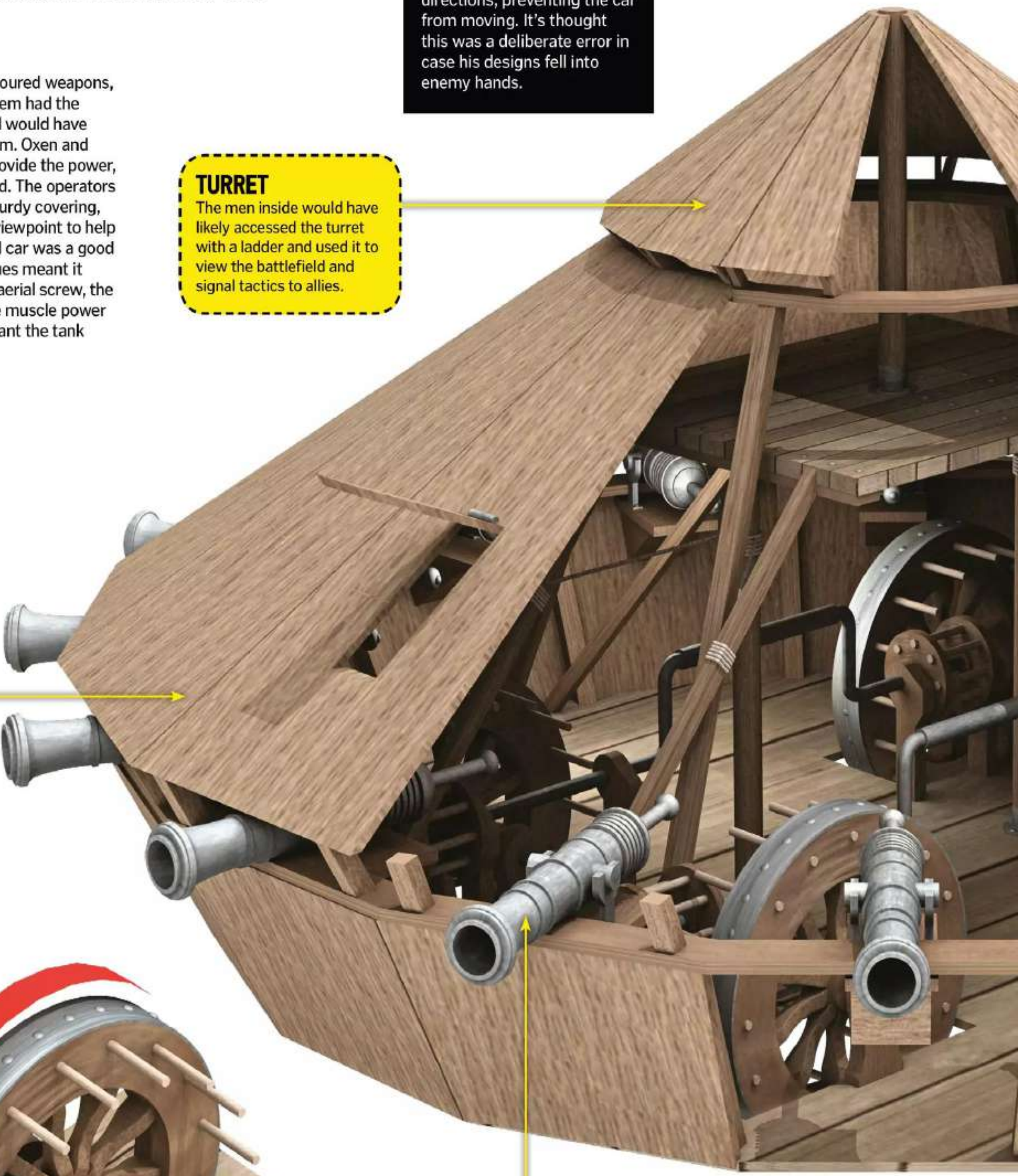
DA VINCI DEVISED A NUMBER OF MILITARY MECHANISMS THAT COULD HAVE REVOLUTIONISED THE BATTLEFIELD

ARMOURED CAR

Incorporating past designs for armoured weapons, da Vinci's tortoise-like cannon system had the ability to move over flat terrain and would have been powered by an eight-man team. Oxen and horses were initially intended to provide the power, but space inside the car was limited. The operators were protected by a slanted and sturdy covering, and a turret on top was used as a viewpoint to help the drivers navigate. The armoured car was a good idea on paper, but a number of issues meant it could never have worked. Like the aerial screw, the human body simply didn't have the muscle power to move it, and the thin wheels meant the tank would easily sink in mud.

WOULD IT WORK?

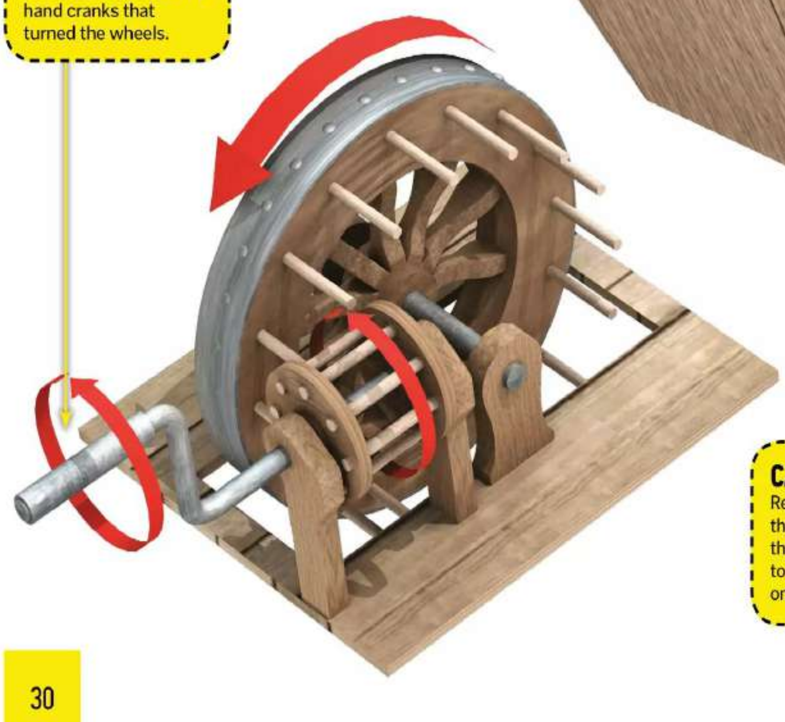
If da Vinci's illustration was followed, the shafts would turn the wheels in opposing directions, preventing the car from moving. It's thought this was a deliberate error in case his designs fell into enemy hands.



TURRET
The men inside would have likely accessed the turret with a ladder and used it to view the battlefield and signal tactics to allies.

ARMOUR
The plated sloping design proposed by da Vinci was possibly superior to World War I tank armour, as the 45-degree angle would help deflect the impact of enemy projectiles.

POWER TRAIN
Da Vinci recommended that his armoured car be powered by a team of eight men, operating hand cranks that turned the wheels.

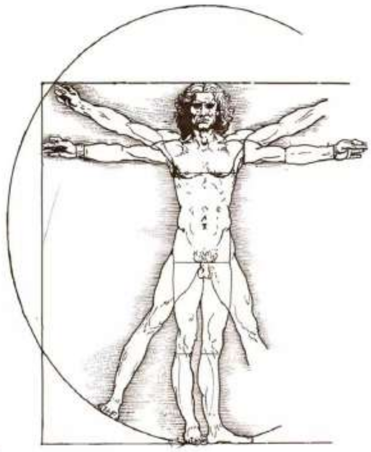


CANNONS
Regularly placed around the car's circumference, the guns would be able to fire in any direction on the battlefield.

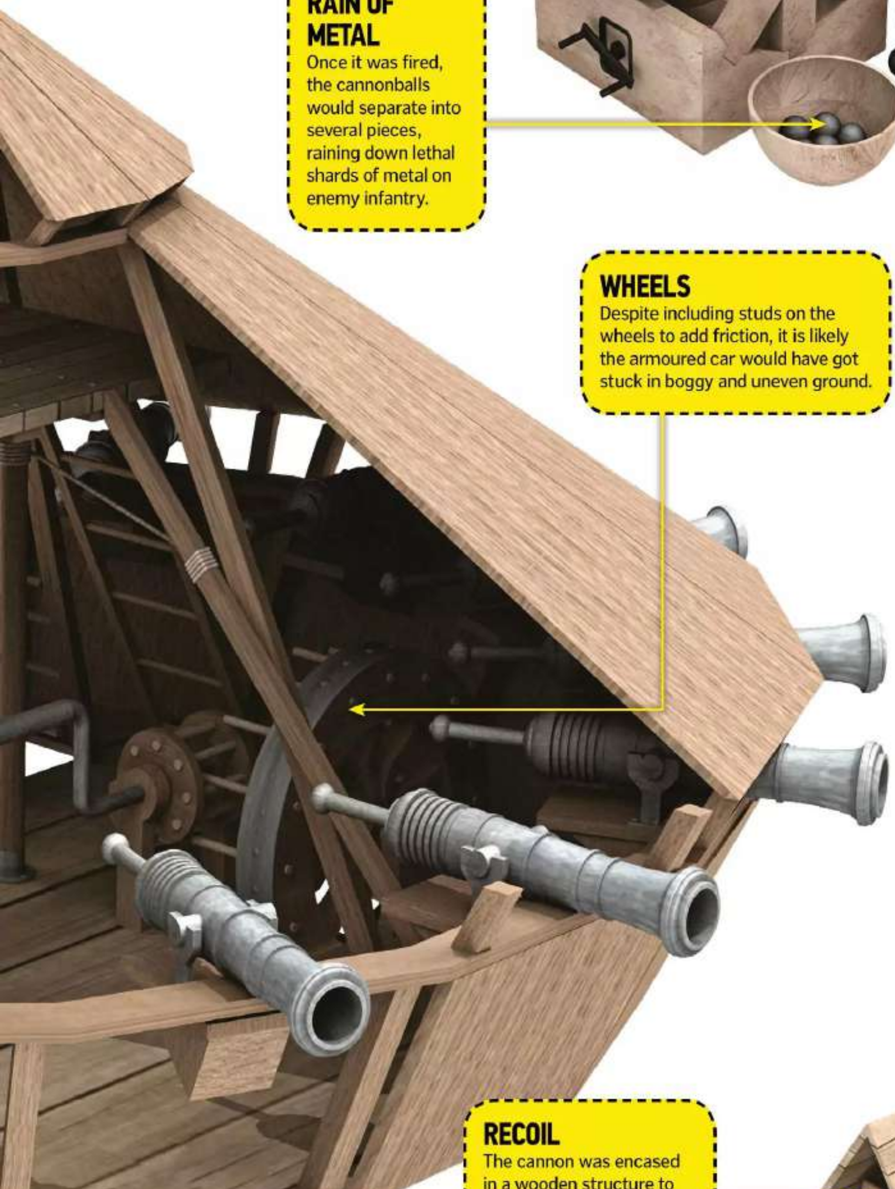
"HIS IDEAS WERE AMBITIOUS, BUT THEY WERE GROUNDED IN LOGICAL CALCULATIONS"

THE BOMBARD
Another weapon that da Vinci depicts in his notebook is a bombard that launched fragmenting ammunition.

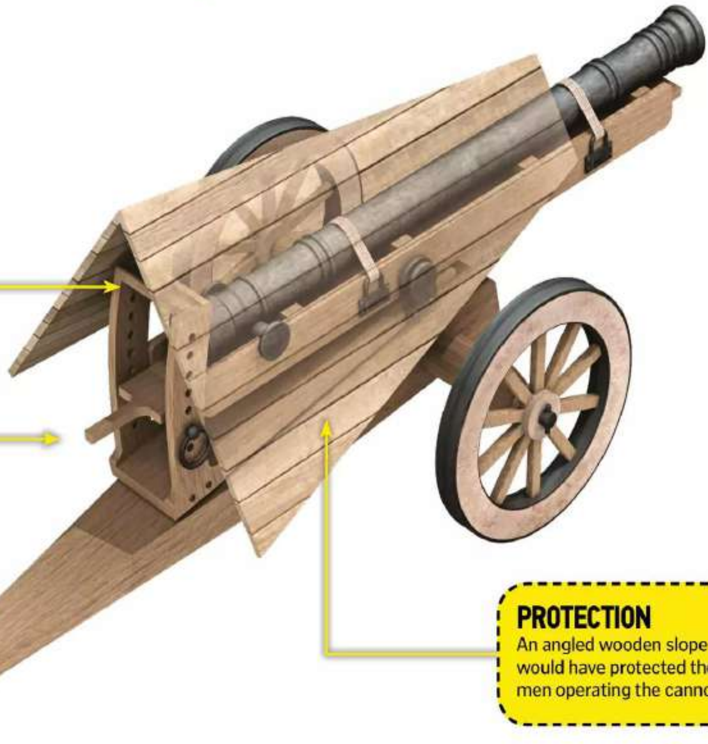
RAIN OF METAL
Once it was fired, the cannonballs would separate into several pieces, raining down lethal shards of metal on enemy infantry.



WHEELS
Despite including studs on the wheels to add friction, it is likely the armoured car would have got stuck in boggy and uneven ground.



MACHINE GUN
Cannons were important in Renaissance-era artillery. Da Vinci aimed to add maneuverability and extra firepower with his concept of a multi-barrelled war machine that could fire a dozen cannonballs at once. With wheels on its side, the portable muzzle-loaded cannon had a rotating body with up to three revolving rows of guns. One could fire while the other two cooled and were reloaded. The recoil would have been fierce, so the machine was equipped with a support bulkhead that held the main body in place. In one of da Vinci's sketches, the barrels are arranged in a fan shape to give the weapon a wider firing range.



RECOIL
The cannon was encased in a wooden structure to hold it in place. Although it was heavy, accurate firing was not difficult.

SPRINGALD
The springald was an artillery device that existed before da Vinci, but like many of his other creations, he built upon the idea. His version had the ability to fire in many directions both horizontally and vertically. An elevating arc moved the springald up and down, and when the desired height was achieved, it was held in place by a cylindrical peg. It could then be aimed to the left and the right. Iron and stone cannonballs, and even metal-tipped arrows were fired from the breech-loaded cannon.

PROTECTION
An angled wooden slope would have protected the men operating the cannon.

HYDRAULIC MACHINES

DA VINCI'S NOTEBOOKS FEATURE SEVERAL IDEAS FOR COMPLEX YET WORKABLE DEVICES POWERED BY WATER

PADDLEBOAT

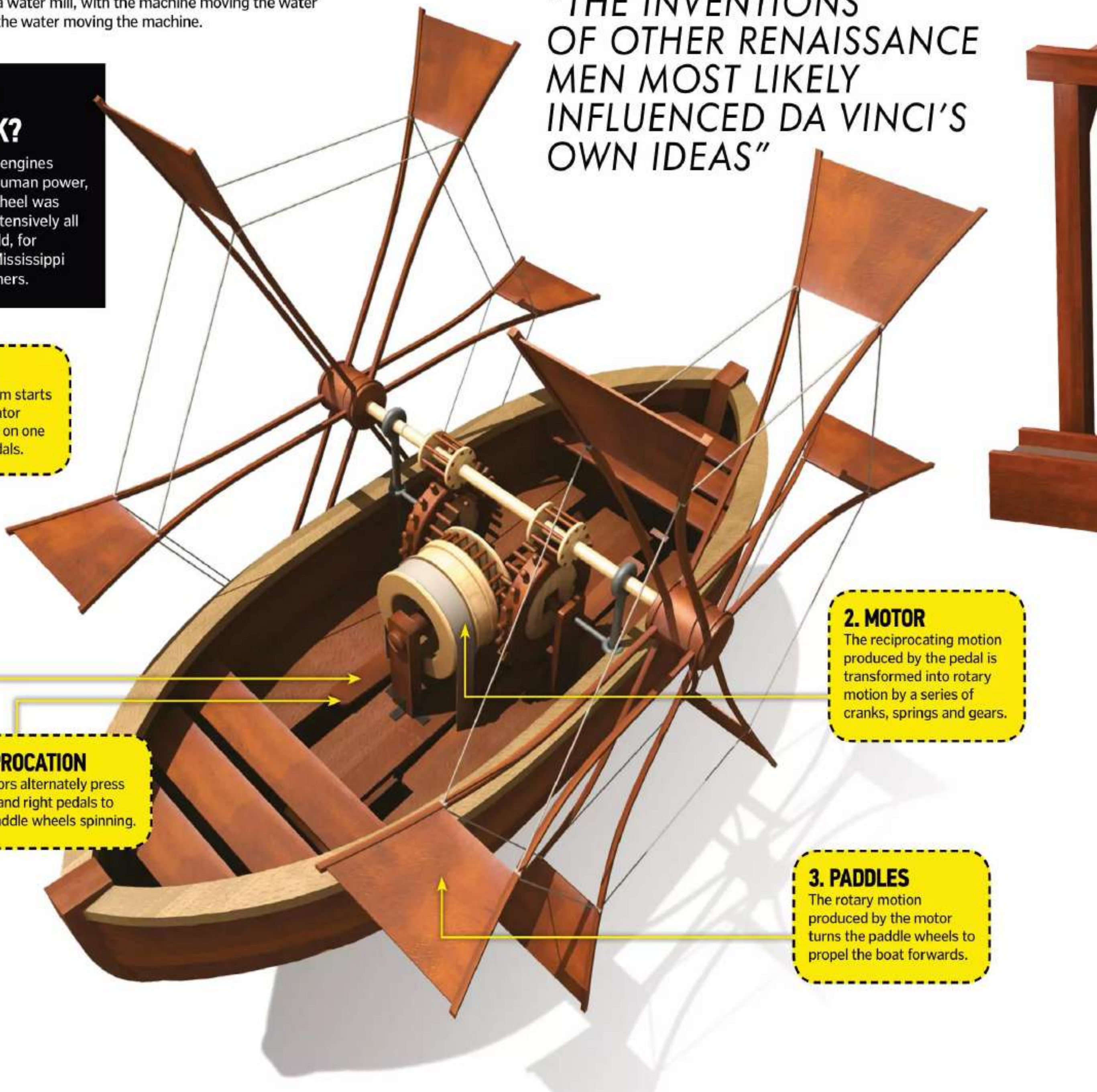
With the absence of internal combustion engines, boats and ships in the 15th century were powered either by wind or by oar. Writing between 1487 and 1489, da Vinci reasoned that a paddle-based mechanism that used reciprocating motion (repetitive back and forth movements) would be far more effective. By replacing the oars with paddle wheels, it would be easier for the boat to travel upstream.

The paddleboat wasn't an original da Vinci idea – Italian inventors Taccola and Francesco di Giorgio had both looked into the concept before – but this was the most realistic and workable proposal yet. The operators would push down on alternate foot pedals, which powered a reciprocating-motion system, which in turn was transformed into rotary motion to turn the paddle wheels and propel the boat forwards. The principle was the opposite of a water mill, with the machine moving the water rather than the water moving the machine.

"THE INVENTIONS OF OTHER RENAISSANCE MEN MOST LIKELY INFLUENCED DA VINCI'S OWN IDEAS"

WOULD IT WORK?

Using steam engines rather than human power, the paddle wheel was later used extensively all over the world, for example in Mississippi paddle steamers.

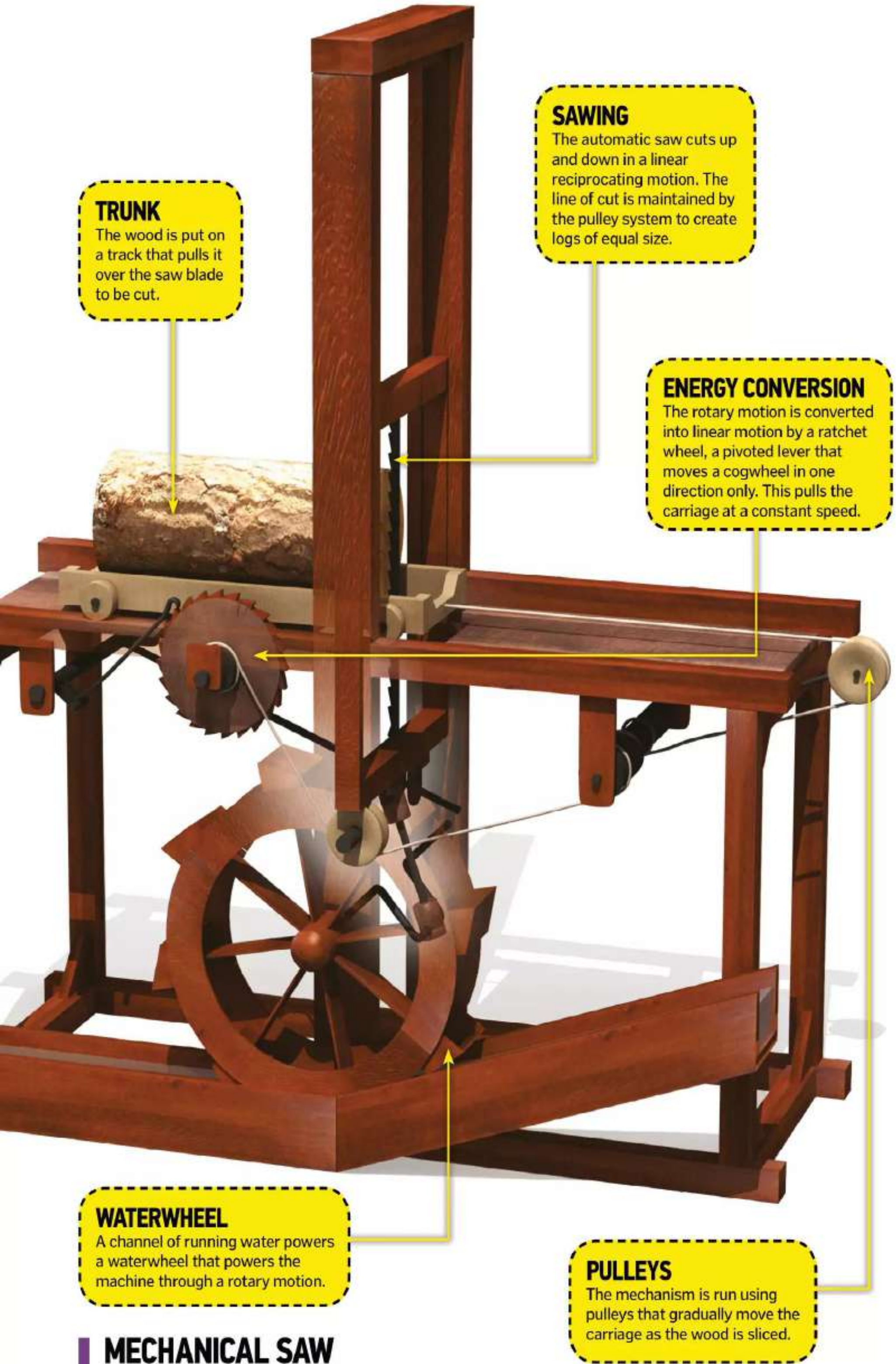


1. PEDAL
The mechanism starts with the operator pushing down on one of the two pedals.

2. MOTOR
The reciprocating motion produced by the pedal is transformed into rotary motion by a series of cranks, springs and gears.

3. PADDLES
The rotary motion produced by the motor turns the paddle wheels to propel the boat forwards.

4. RECIPROCATION
The operators alternately press on the left and right pedals to keep the paddle wheels spinning.



MECHANICAL SAW

Noted down circa 1478, da Vinci's mechanical saw was a rapid cutting device. The saw utilised the energy of a water mill to power the slicing of logs into wood. The wood would then be used for construction, particularly in war time, where it would be used to quickly build military bridges (these bridges were easy to transport and could be rapidly assembled across a body of water to allow troops to cross).

The saw's mechanism was relatively simple: a channel of running water turned a mill, and this rotary motion was transformed into linear reciprocating motion that powered the up and down sawing movement. The mechanism also powered pulleys and crankshafts that kept the log moving towards the saw. Like the paddleboat, the mechanical saw had been thought of before but not in this level of detail. Once again, da Vinci took a clever concept and improved it.

WOULD IT WORK?

The mechanical saw was one of da Vinci's least innovative but most workable concepts. Its automatic cutting system worked using the same principles as a standard water mill.

DA VINCI INVENTIONS USED TODAY

Ball bearings

First seen in a drawing in 1497, da Vinci based his idea on Ancient Egyptian rollers that were used to transport huge stones up ramps to allow the construction of the famous pyramids.

Double hull

Da Vinci proposed the idea that a double hull would stop ships from sinking if its first was pierced by an enemy ship's ram, a weapon commonly used in naval battles.

Parachute

Da Vinci devised this combination of linen cloth and wooden poles 300 years before the first parachute test. His design was tested in 2005 and was proved to work.

Robot

Using a system of pulleys, weights and gears, da Vinci's robot was a moving suit of armour that could move its limbs, turn its head and sit down and stand up.

Air conditioning

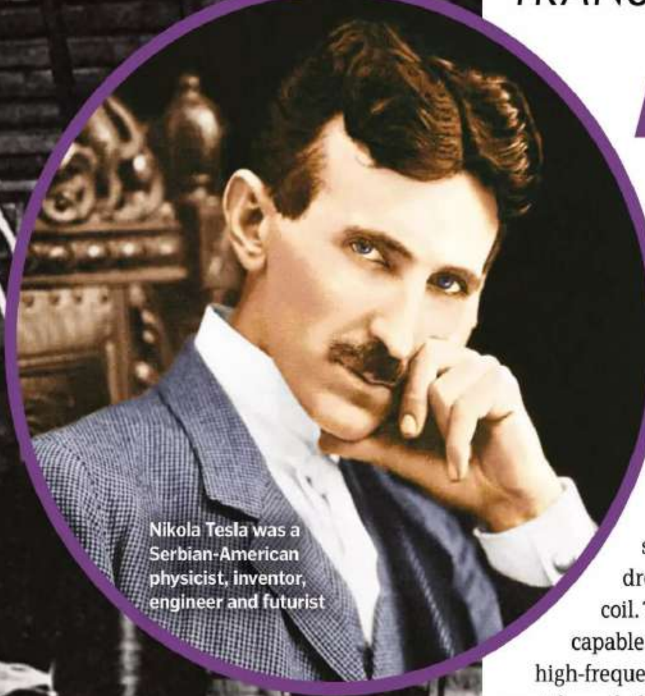
After being asked to help ventilate a boudoir, da Vinci developed a mechanical water-driven fan in 1500 that can be seen as a precursor to our modern cooling systems.

THE TESLA COIL

HOW ONE OF HISTORY'S GREATEST INVENTORS PRODUCED A SPECTACULAR LIGHT SHOW

In this double-exposure photograph, Tesla appears to sit in his Colorado Springs laboratory while a Tesla coil sends sparks through the air

"TESLA BEGAN TO BUILD A 57-METRE TALL TOWER THAT COULD WIRELESSLY TRANSMIT ENERGY"



Nikola Tesla was a Serbian-American physicist, inventor, engineer and futurist

After inventing the ground-breaking alternating current (AC) motor in 1887 – the device that is used to power many of the electrical gadgets that we use in the modern day – Nikola Tesla set his sights on a different and more challenging dream: a world without wires.

Tesla envisioned a series of giant transmission towers that could provide the entire globe with an endless supply of wireless electricity, and his first step towards achieving this dream was the eponymous Tesla coil. This revolutionary device was capable of producing high-voltage, high-frequency AC electricity that could be sent through the air.

The Tesla coil consisted of two main parts: a flat primary coil and a taller secondary coil, both made of thick copper wire. When switched on, a transformer connected to the mains power supply converted the low voltage power into high voltage power, stepping it up to thousands of volts. It was stored in a capacitor, just like a modern battery, and when it was fully charged, it was sent flowing through the primary coil.

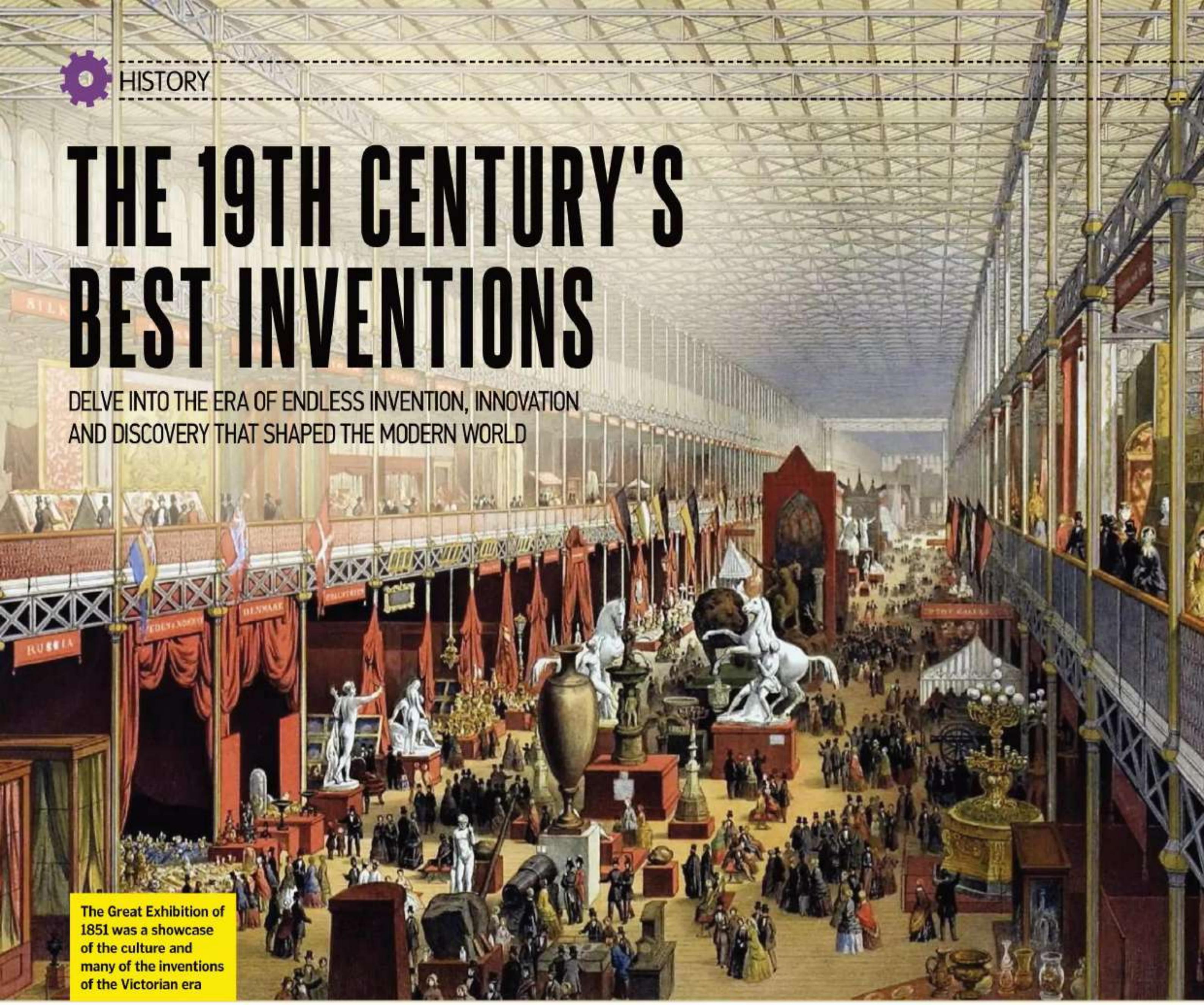
This created a strong magnetic field, which generated an electric current in the secondary coil through electromagnetic induction. Energy quickly flowed back and forth between the two coils several hundred times per second, building up charge in an additional capacitor that was attached to the secondary coil. Eventually, the charge in this capacitor became so great that it escaped, sending sparks flying through the air and illuminating light bulbs that were several metres away.

After wowing onlookers with this spectacular light show, Tesla began to build a 57-metre tall tower that could wirelessly transmit energy across great distances using this technique. However, construction was soon abandoned when he failed to secure enough funding to keep the project going. Although he fell short of achieving his dream of a wireless world, variations of his Tesla coil are still used in radios and televisions to this day.

The Magnifying Transmitter tower was designed by Tesla to deliver wireless electricity around the world

THE 19TH CENTURY'S BEST INVENTIONS

DELVE INTO THE ERA OF ENDLESS INVENTION, INNOVATION AND DISCOVERY THAT SHAPED THE MODERN WORLD



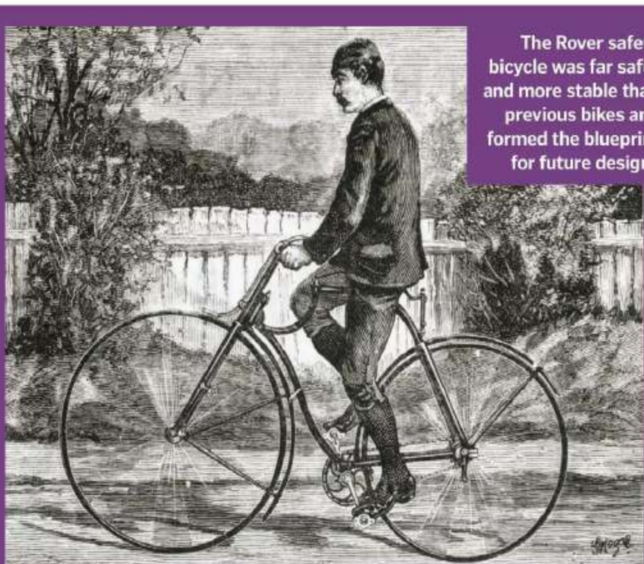
The Great Exhibition of 1851 was a showcase of the culture and many of the inventions of the Victorian era

Everything from selfies to sound systems, and iMacs to milkshakes owe their existence to the scientists and engineers of the 1800s. Motorcars, steam trains and even the humble bicycle enabled people to travel across vast distances quickly and cheaply for the first time. Studies of microbiology enhanced our understanding of diseases, leading the way to cures and immunisation, while the telephone, radio and telegraph revolutionised the way in which we communicate, connecting people across countries and continents. Here are just a few of the most important inventions and discoveries for which we can thank the geniuses of the 19th century.

1817-1880S
BICYCLES

Although there are designs for two- and four-wheeled human-powered vehicles dating back all the way to the 15th century, the first successful, safe and popular human-powered bikes did not begin to emerge until some 400 years later. In 1817, German aristocrat Karl von Drais designed the Laufmaschine ('running machine'), which was simply two wheels on a wooden frame and a seat. To propel the machine, the rider would simply run on the ground, then raise their feet and let the wheels do the work.

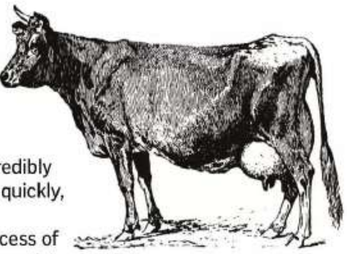
By the 1860s a pedalled bicycle, called the velocipede, had been developed in France, which enabled riders to rotate the front wheel by foot. This was also known as the 'boneshaker' due to the uncomfortable ride caused by its solid wheels. By the 1880s the modern bike had taken shape, with the pedals moved to the centre of the frame, powering the rear wheel via a chain to enable greater control and stability.



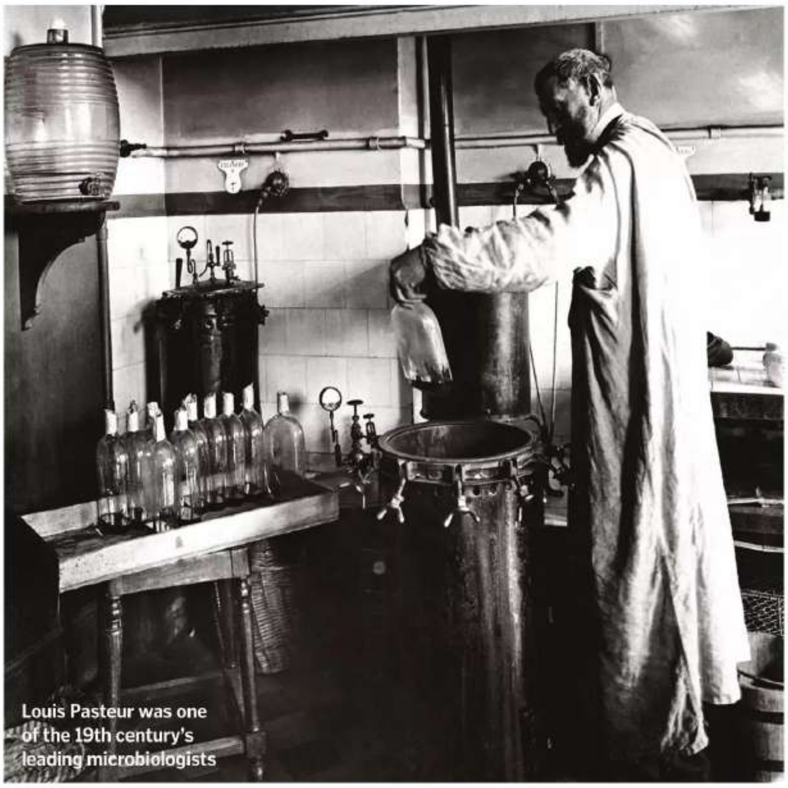
The Rover safety bicycle was far safer and more stable than previous bikes and formed the blueprint for future designs

"THE RIDER WOULD SIMPLY RUN ON THE GROUND, THEN RAISE THEIR FEET"

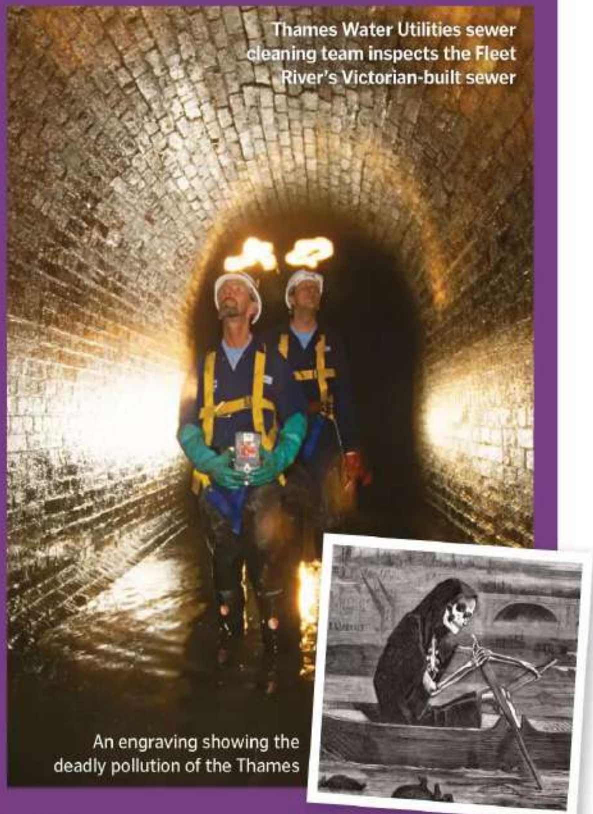
1865
PASTEURISATION



Before the mid 19th century, food and drink had an incredibly short shelf life, and in particular milk deteriorated very quickly, becoming foul smelling, undrinkable and wasted. This changed with the development of pasteurisation, a process of heating liquid until almost boiling to destroy as many harmful microorganisms as possible before rapidly cooling it. Chemist Louis Pasteur made his discovery while researching the fermentation process of wine. He was attempting to discover the cause of sour or spoiled wine and found that the rapid heating and cooling prevented any germs or microbes causing contamination. His studies also created a greater understanding of the role of living microorganisms during fermentation. The Frenchman lent his name to his discovery, which today is a vital stage in the mass production of dairy and alcohol products. However, his research into microbiology, or germ theory, also led to a greater understanding of the causes of and cures for diseases.



Louis Pasteur was one of the 19th century's leading microbiologists



Thames Water Utilities sewer cleaning team inspects the Fleet River's Victorian-built sewer

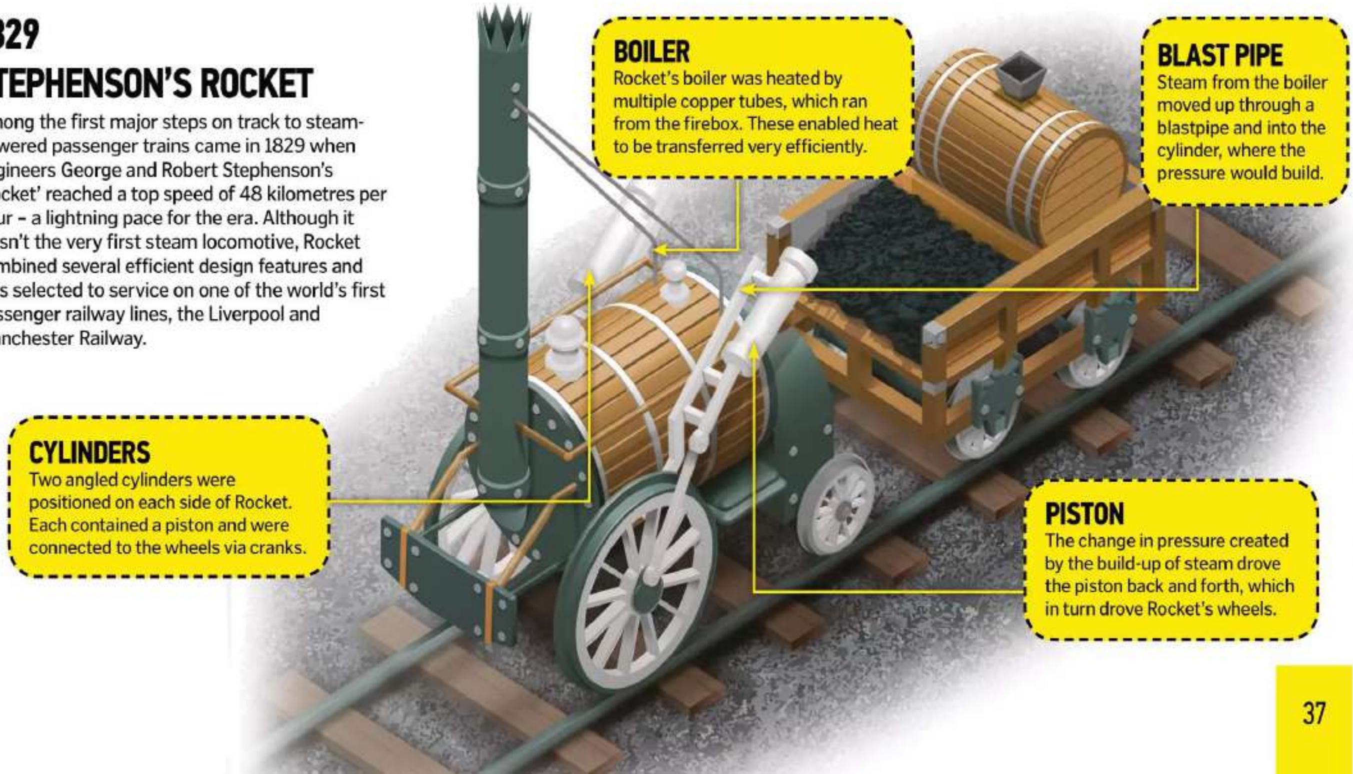
An engraving showing the deadly pollution of the Thames

1866
LONDON'S SEWER SYSTEM

In the early 19th century, the River Thames was a stinking cesspit of raw sewage. Disease was rife and more than 10,000 Londoners were killed by cholera between 1853 and 1854. One particularly hot summer brought the city to a standstill in what was called the 'Great Stink', finally prompting the government to take action. Chief engineer Joseph Bazalgette constructed an underground network of 'intercepting sewers' that collected the waste that flowed out to the Thames using gravity and the occasional huge steam pump. The sewers were dug by hand – mechanical diggers didn't exist – and constructed using 318 million bricks and new water-resistant Portland cement. However, the sewage still wasn't 'treated' until the 1880s.

1829
STEPHENSON'S ROCKET

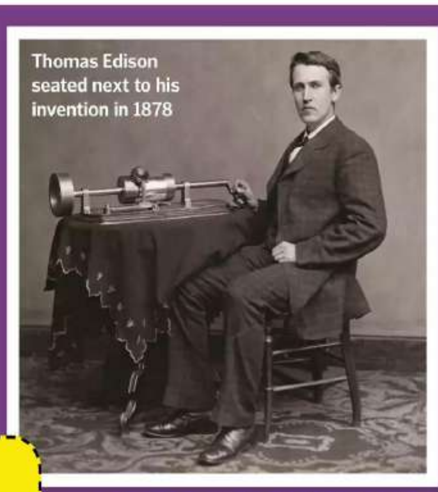
Among the first major steps on track to steam-powered passenger trains came in 1829 when engineers George and Robert Stephenson's 'Rocket' reached a top speed of 48 kilometres per hour – a lightning pace for the era. Although it wasn't the very first steam locomotive, Rocket combined several efficient design features and was selected to service on one of the world's first passenger railway lines, the Liverpool and Manchester Railway.



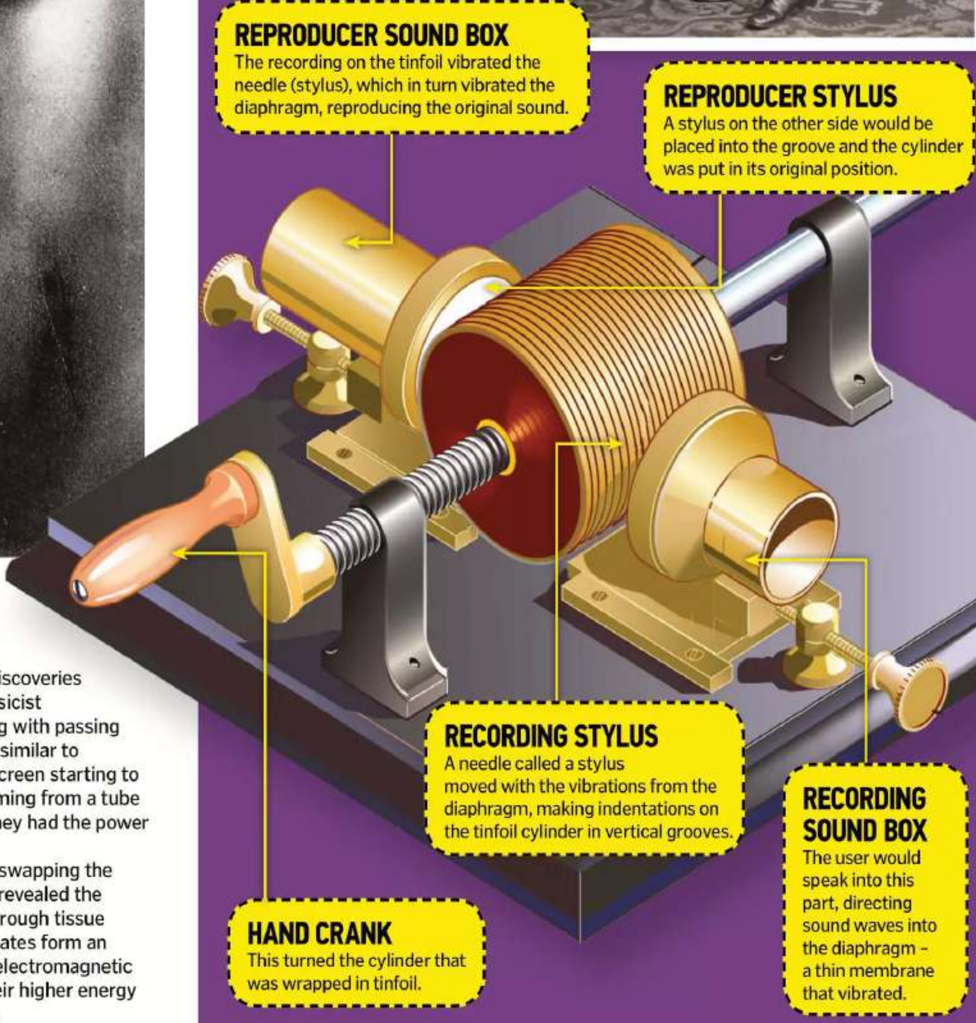
The first-ever X-ray was of Anna Bertha Röntgen's hand

1877 PHONOGRAPH

A cross between the telephone and telegraph, this unusual contraption could both record sound and play it back. Its inventor, Thomas Edison, envisioned it being used for dictating letters, recording lessons in school or recording phone conversations, to name a few applications. The first words he recorded were "Mary had a little lamb" and he was amazed when the machine played his words back.



Thomas Edison seated next to his invention in 1878



1895 X-RAYS

One of the 19th century's most important discoveries happened entirely by accident. German physicist Wilhelm Conrad Röntgen was experimenting with passing electrical currents through gas-filled tubes, similar to fluorescent light bulbs, when he noticed a screen starting to glow. It was illuminated by invisible rays coming from a tube that was covered in black paper, meaning they had the power to penetrate solid objects.

Röntgen created the first X-ray image by swapping the screen for a photographic plate. The image revealed the bones in his wife's hand. The rays passed through tissue easier than bone, and the 'shadows' this creates form an image. X-rays are a type of high-frequency electromagnetic radiation similar to light but, unlike light, their higher energy means they can pass through most objects.

AN AGE OF PROGRESS

1839 – Light-sensitive photographic paper
William Henry Fox Talbot
By using light-sensitive silver nitrate, Talbot created 'photogenic drawings'.

1840 – Adhesive postage stamp
Sir Rowland Hill
The Penny Black features a profile image of Queen Victoria.

1843 – Christmas card
Sir Henry Cole
Henry Cole was too busy to write to his friends over the holiday season, so commissioned the first Christmas card.

1844 – Morse Code
Samuel Morse

1845 – Rubber tyres
Robert Thomson

1846 – Sewing machine
Elias Howe
This was not the first sewing machine, but Howe's refined design has much more in common with our modern machines.

1848 – Modern water turbine
James Francis

1849 – Concrete
Joseph Monier

1849 – First glider to be flown by a pilot
George Cayley

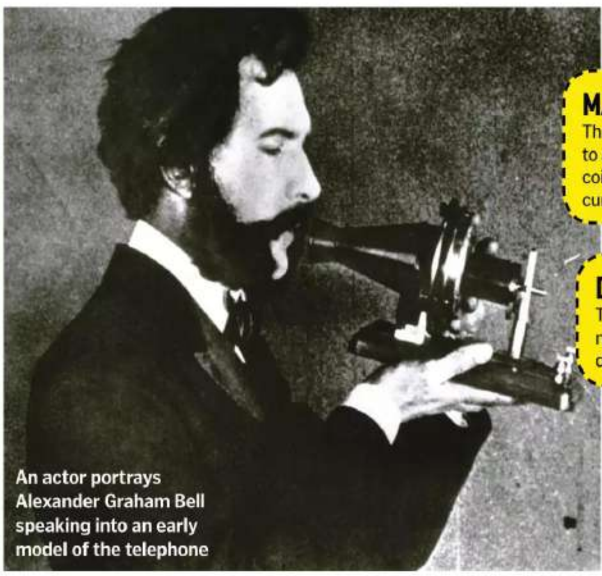
1851 – Public flushing toilets
George Jennings

THE EVOLUTION OF PHOTOGRAPHY

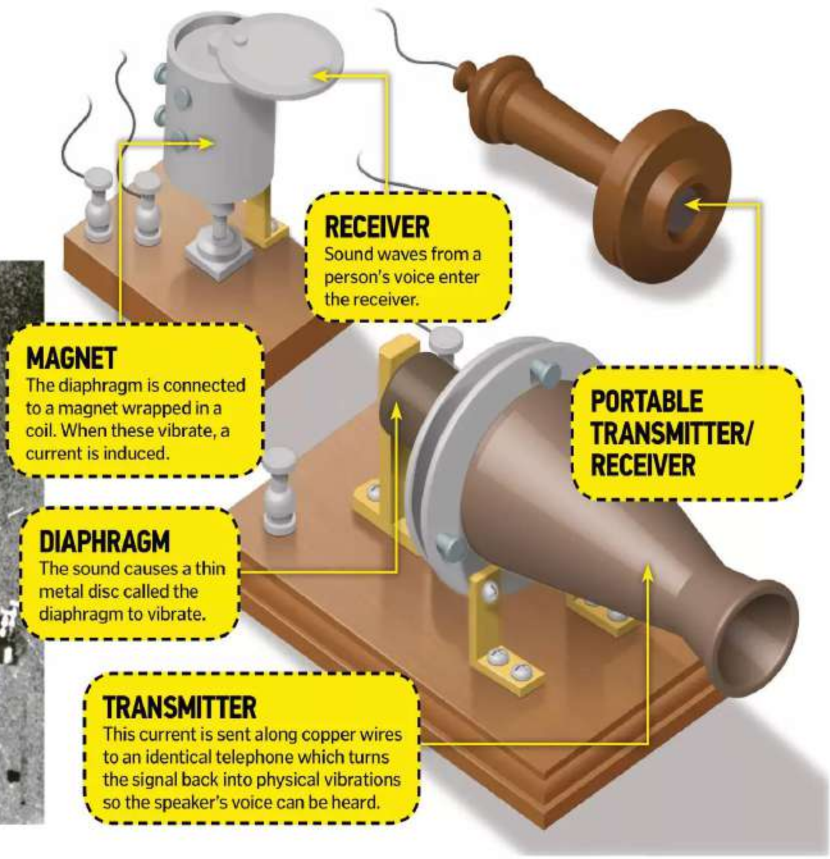
A SNAPSHOT OF CAMERAS THROUGH TIME

1876
TELEPHONE

The first words ever spoken on the telephone were: "Mr Watson, come here; I want to see you." It was inventor Alexander Graham Bell talking to his assistant on 10 March 1876. The telephone he created looked very different to its modern counterparts, but operated using a mouthpiece, transmitter and a receiver.



An actor portrays Alexander Graham Bell speaking into an early model of the telephone



1853


Post box
Richard Redgrave
The unusual octagonal design was made by John M Butt & Co of Gloucester, England.

1854
Turning iron into steel
Henry Bessemer

1863


Underground railway
London's Metropolitan Railway opened between Paddington and Farringdon Street.

1873


Typewriter
Christopher Sholes
The first commercially successful typewriter included the QWERTY keyboard.

1873
Denim jeans
Jacob Davis and Levi Strauss

1879


Electric light bulb
Thomas Edison
He wasn't the first to develop the light bulb, but Edison improved the design so it lasted longer.

1885
Three-wheeled motor car 'motorwagen'
Karl Benz

1887


Gramophone
Emile Berliner
Berliner was the first person to record on flat discs that could be mass produced.

1895
Cinematograph
Lumière brothers
This motion picture film camera also doubled as a projector.

1895
Wireless communication
Guglielmo Marconi

MEDIEVAL WRITING EQUIPMENT

WHY WE USED QUILLS FOR OVER 1,300 YEARS

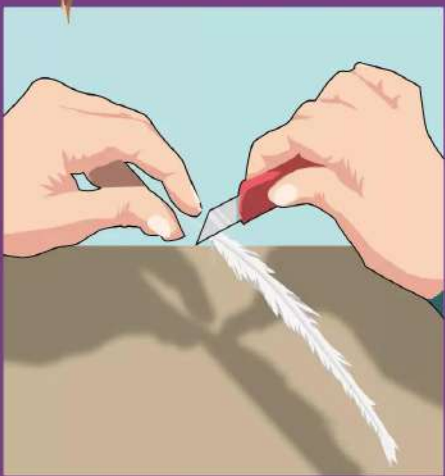
Before the invention of the pen, most people used quills to write with. These were stripped bird feathers, usually from geese. In particular, swan feathers were very sought after but geese, crow, owl and turkey feathers were simpler to obtain.

Quills were easy to supply, comfortable to hold and tapered down to a point so the writer could create all the subtle curves and lines of fine handwriting.

The first record of their use was around the 6th century by European monks, replacing the reeds they had been using up until then. Feathers were stripped, buried in hot sand to harden, hollowed out and then filled with ink. They were time-consuming to make and had to be refilled and reshaped regularly, but continued to be the main writing implement until the metal pen became popular in the mid-19th century.

HOW TO MAKE A QUILL

TRAVEL BACK THROUGH TIME TO THE MIDDLE AGES AND WRITE WITH FEATHERS



Prime your feather

Scout around near a river or lake for a feather that has been dropped by a swan or goose. Ideally it should be around 15cm long and intact. Using a Stanley knife, very carefully shave off the fluffy feathers at the pointy end. You should be able to grip the quill without touching any feathers. Then place the feather in a bowl of water and leave it overnight to soak.

Toughen and shape

Heat sand in the oven at 175°C and bury the feather, using oven gloves to avoid burns. Wait until the sand has cooled and remove the hardened feather. From about 2.5cm above the tip, slice down at an angle of around 45 degrees to the tip of the feather. Make a small, flat cut on the opposite side of the tip. There should now be two spikes on the tip that you need to pinch together.

Finishing off

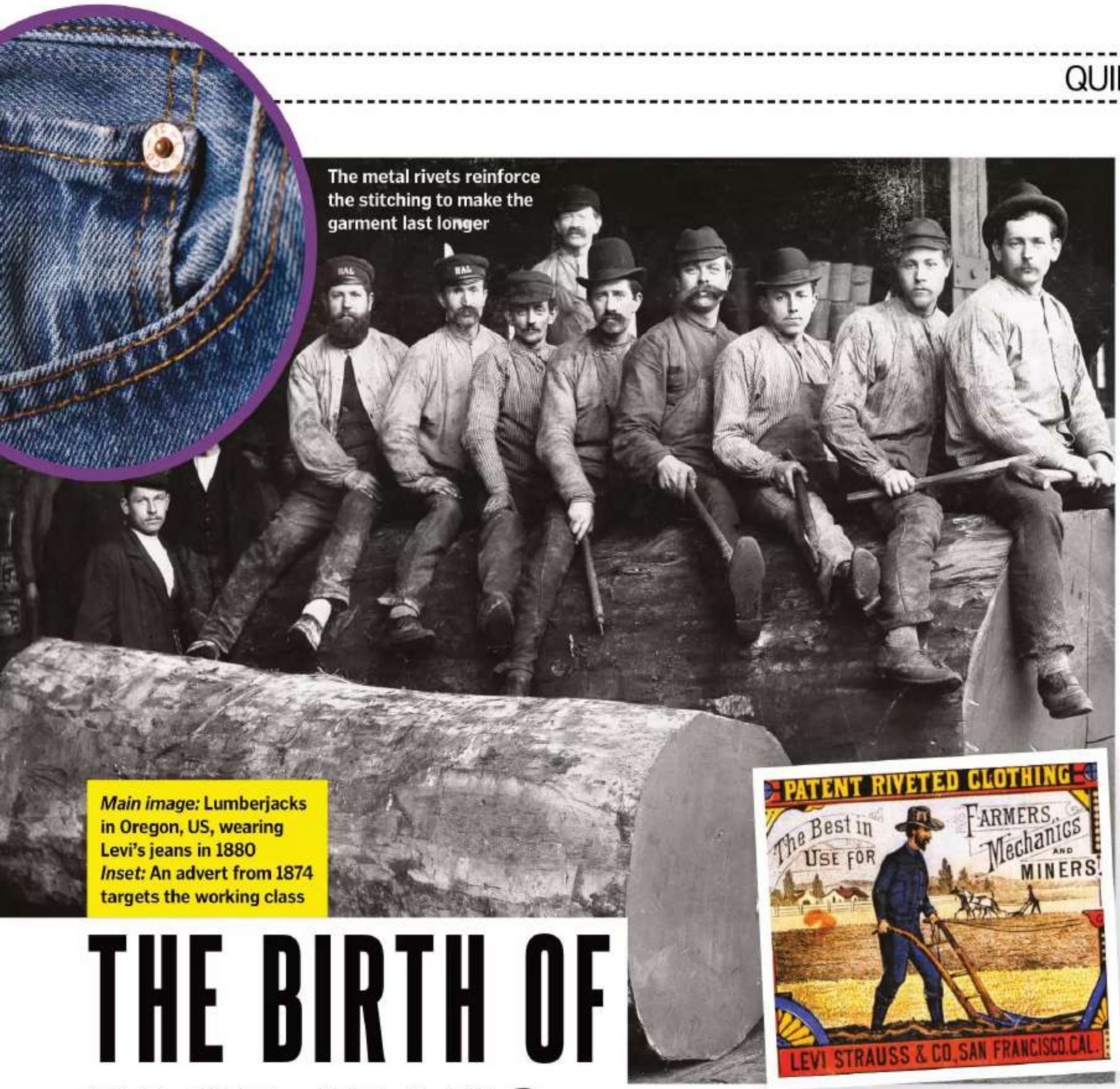
Shave the pinched end so it is nice and smooth and you should have a feather tapering nicely to a point. Dip your quill in the ink where it should soak up the writing fluid. There should be enough to write a fair few lines, depending on how tightly you've pinched it together. The tighter you've pinched it, the more ink it should retain. Take it out and begin writing like a Medieval scribe!

THE FIRST HEARING AIDS

FROM 19TH-CENTURY EAR TRUMPETS TO MICROCHIPS

Although they may look like something out of a cartoon, ear trumpets were used frequently throughout the early 19th century. The first type of hearing aid had a large surface area that amplified sound that was directed toward the ear. They were made of metal, silver, wood or animal horns, and were incredibly bulky. However, as their use became more widespread, they featured a collapsible design so the ear trumpet could be carried in pockets and removed when necessary. Horns were so popular that even midwives would use a similar instrument to the ear trumpet for listening to pregnant ladies' wombs.

Early hearing aids could hardly be described as 'inconspicuous'



The metal rivets reinforce the stitching to make the garment last longer

Main image: **Lumberjacks in Oregon, US, wearing Levi's jeans in 1880**
Inset: **An advert from 1874 targets the working class**

THE BIRTH OF BLUE JEANS

THE 'RIVETING' STORY OF HOW TWO VISIONARY IMMIGRANTS CREATED AN AMERICAN CLASSIC

Denim jeans are a fashion essential around the world, but their origins are much more humble. During the late 1800s, America was in the full throes of the Gold Rush, and Jacob Davis, a Latvian immigrant, was working as a tailor in Nevada. Jacob sold clothing to local miners and workmen, who required strong and hard-wearing material for their work. It was here that Jacob struck gold.

By fixing small copper rivets to the most strained areas of the garment, such as the pockets, he created a much more durable design. This new, robust clothing caught public attention and Jacob's 'waist overalls', as they were known, became so popular that he sought a patent to protect his idea. But a patent required money, so he asked his fabric supplier, Levi Strauss, for help.

Bavarian-born Strauss had also travelled to the States to seek his fortune and saw potential in Jacob's product. The pair were granted a patent in 1873 and before long the modern denim jean was being worn in factories, farms and mines across the country. Indigo was chosen to dye the jeans because it was dark enough to hide stains, it didn't penetrate the woven fabric and, crucially, it was cheap.

When the patent expired in 1908 dozens of imitations flooded the market ,and in the decades to come, they were worn by men and women of all classes. Teenagers began calling them 'jeans' instead of 'overalls', and manufacturers officially adopted the term in the 1960s. Today their popularity is as durable as the original riveted design.

DENIM BY THE DECADES

HOW HAVE JEAN STYLES CHANGED OVER THE YEARS?

5 JEAN-IUS FACTS

Denim jeans is a misnomer

In the late 1700s, two cotton fabrics were produced: denim and jean. Denim, originally made in de Nîmes, France, was more durable and thicker than jean, used to make workers' trousers in Genoa, Italy.

They were almost banned

Jeans gained a 'bad boy' image after featuring in movies like *Rebel Without a Cause*. Schools began banning them, so Levi's ran a campaign starring a clean-cut, denim-clad kid with the slogan 'Right for school'.

Levi wasn't his real name

He was born Loeb Strauss, but like his future business partner, Jacob Davis, he changed his name after immigrating to the US. Levi eventually set up a wholesale dry goods business in San Francisco.

Duck or denim?

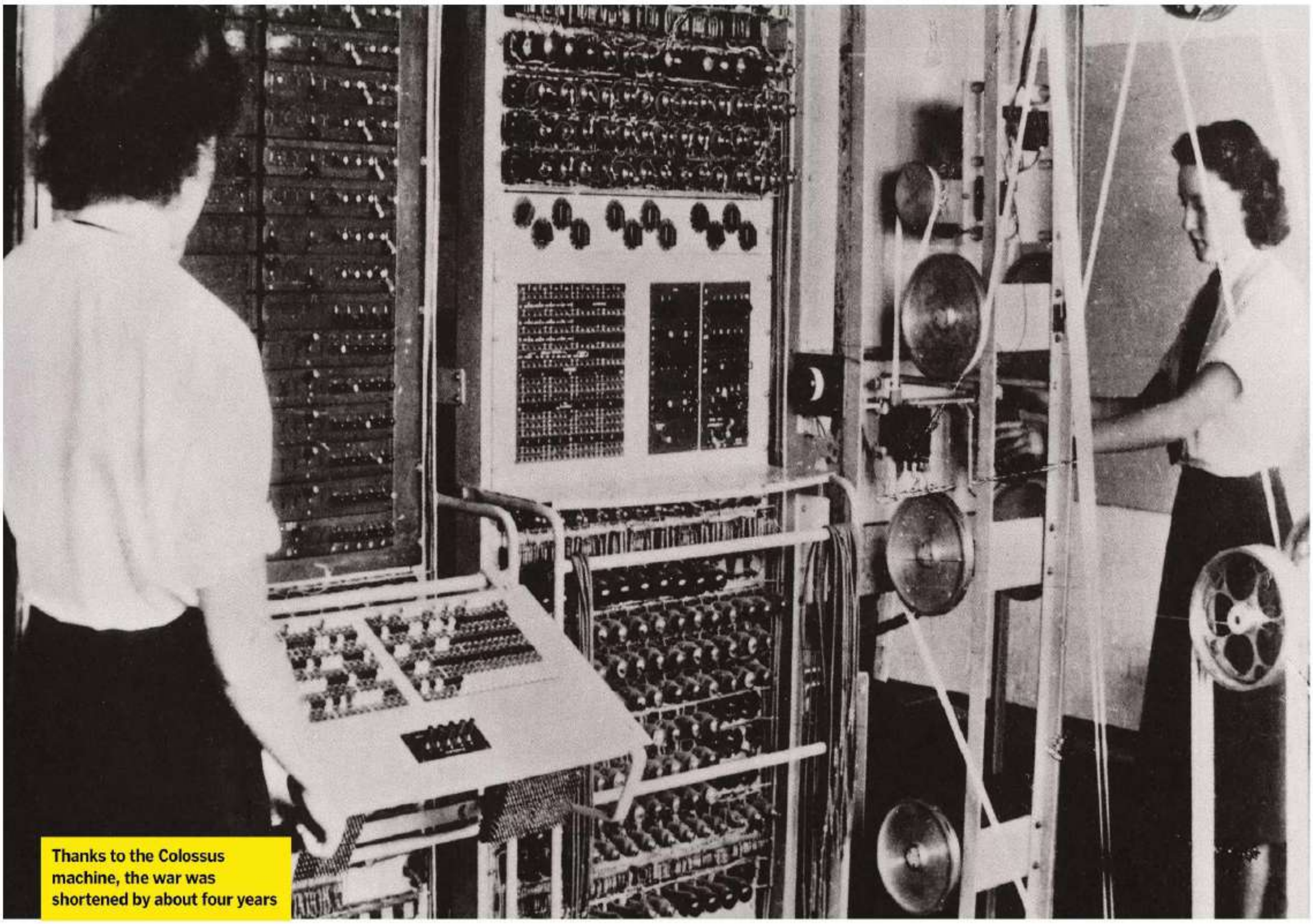
When Levi and Jacob began mass-producing their waist overalls, they manufactured two kinds. One was from blue denim and the other from brown cotton duck – a tough canvas material that was used to cover wagons.

Built to last

In the Levi Strauss & Co archives lies two pairs of jeans dating from the late 1870s or early 1880s that are thought to be the oldest in existence. Only two people know the combination to the fireproof safe that protects them.

COLOSSUS COMPUTER

HOW THE FIRST PROGRAMMABLE DIGITAL COMPUTER HELPED BRING WWII TO AN END



Thanks to the Colossus machine, the war was shortened by about four years

The Colossus computer was a machine used by the British intelligence service during World War II to analyse and decrypt teleprinter orders and messages enciphered with a Lorenz SZ40/42 encryption machine by the Nazi Germany High Command. The contents of the messages were of incredible value to the Allies, as they often contained key orders for German generals, including troop movements and tactics.

Prior to the German use of the Lorenz cipher, the Allies had successfully cracked their Enigma code and had for years held the ability to decode messages thanks to Alan Turing's incredible electromechanical Bombe machine. The Lorenz cipher was much more complex, however, with the SZ40/42 enciphering a message by combining its characters with a keystream of characters generated by 12 mechanical pinwheels. As such, without knowing the key characters – ie the position of the pinwheels – no decryption could take place.

The Colossus solved this issue by finding the Lorenz key settings, rather than actually decoding the message – the latter part was done manually by cryptologists. The computerised process involved the Colossus analysing the inputted encoded message's characters and then counting a statistic based on a programmable logic function (such as whether an individual character is true or false). By analysing a cipher text in this way a number of times, the initial position of the Lorenz machine's 12 pinwheels could be determined and thus the keystream could be established.

Historically, the Colossus proved to be a colossal success, with the Allies decoding many war-changing messages throughout 1944 and 1945 and the generated intelligence used to counter the Nazis' movements in Europe. In addition, after the war, the technological advancements in computing brought about by Colossus led to Britain becoming a pioneering centre for computer science.

A COLOSSAL RECONSTRUCTION

As part of the transformation of Bletchley Park into a museum, a fully functional replica of the Mark 2 Colossus was completed in 2007 by a team of engineers led by electrical engineer Tony Sale. Unfortunately, this was nowhere near as simple as the six decades' worth of technological advancement since the war might make you think, with many blueprints and original hardware being destroyed after World War II, leaving those responsible for its reconstruction severely lacking in workable information.

Luckily though, after a dedicated research campaign, many of the Bletchley team's original notebooks were acquired, which when collated delivered a surprising amount of information. As such, by using the notebooks and consulting several original members of the Bletchley team, including the designer of the Colossus' optical tape reader – Dr Arnold Lynch – the reconstruction was completed successfully and is today situated in exactly the same position of the original Colossus at Bletchley Park, where it can be used to crack codes once more.

A sculpture to commemorate Flowers, with his son (left)

FLOWERS IN FOCUS

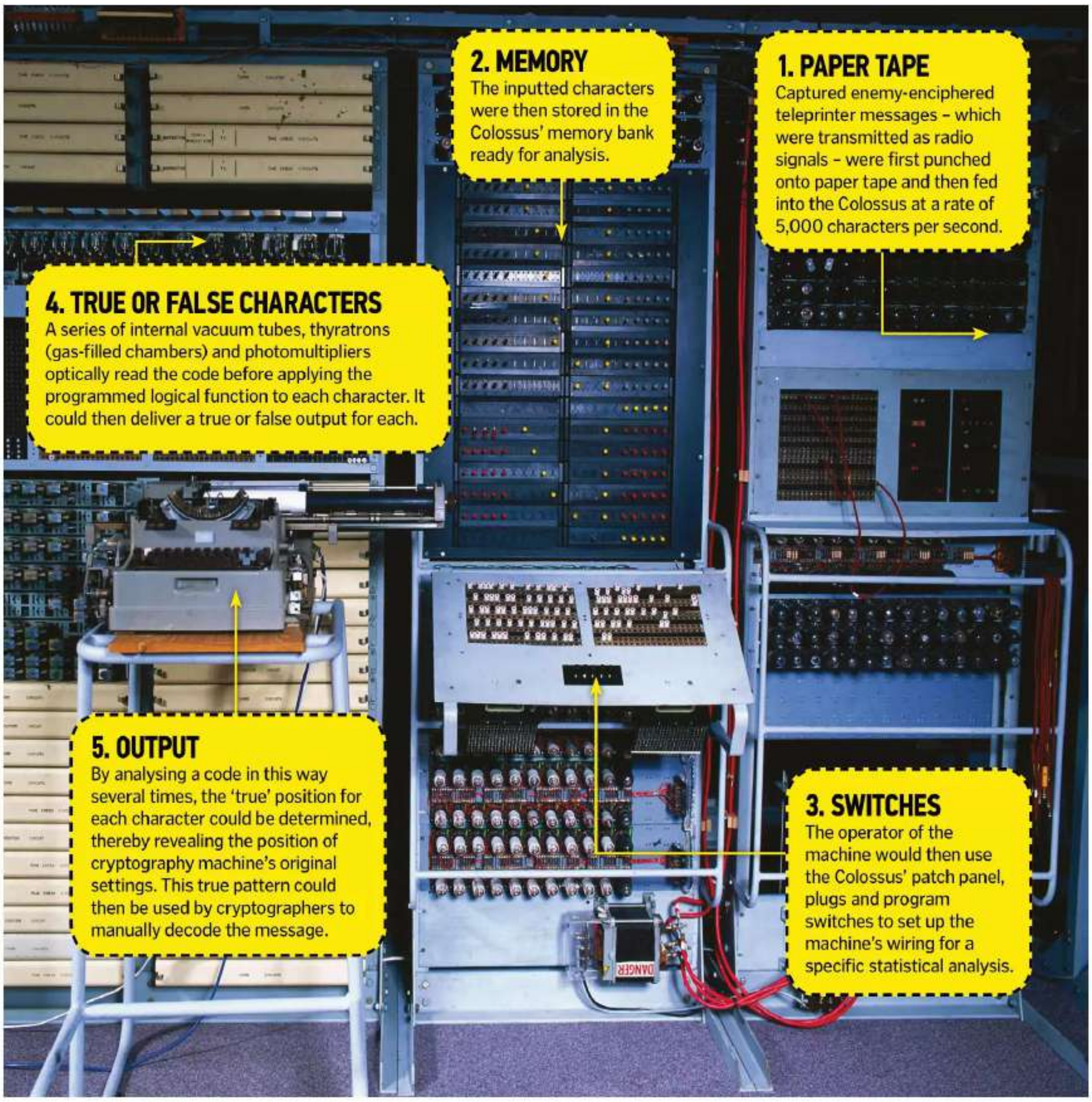
Thomas (Tommy) Flowers was the British engineer behind the revolutionary design and construction of the Colossus computer. After graduating from the University of London with a degree in electrical engineering, Flowers went on to join the telecommunications branch of the General Post Office, where he explored the use of electronics for telephone exchanges.

Off the back of this work, Flowers was invited to help code-breaking expert Alan Turing to build a machine that could help automate part of the cryptanalysis of Nazi Germany's Lorenz cipher – a high-level cipher used to communicate important orders from the high command.

By 1943 Flowers had built the Colossus, and soon after received funding to create a second improved variant, which went into active service in June 1944. Despite his key role in helping the Allies to victory, Flowers could not talk about his work for decades after the war as he was sworn to secrecy.

GUIDE TO CRACKING CODES

UNDERSTAND HOW THIS DECIPHERING MACHINE WORKED STEP BY STEP



In 1993, Bletchley Park was re-opened as a museum devoted to codebreakers

BLETCHLEY'S ROLE IN WWII

Bletchley Park was the British government's main decryption headquarters throughout World War II. Located in Milton Keynes in Buckinghamshire, England, Bletchley was a top-secret facility for Allied communications, with a diverse team of engineers, electricians and mathematicians all working manually – and later with the help of decryption machines – to break the various enemy codes used to disguise orders and private communiqués.

Among the many decoders – also known as cryptanalysts – working at Bletchley, Alan Turing became by far the most famous, with his work in breaking the Enigma and then Lorenz codes earning him the nickname the 'Father of Computer Science'. Indeed, between them, Turing, Flowers and the rest of the Bletchley team's efforts arguably were crucial to the Allies' eventual victory in 1945, with the intelligence gathered by them – intel which was code-named 'Ultra' – speculated by some to have shortened the war by up to four years.

Today Bletchley Park is run by the Bletchley Park Trust, which maintains the estate as a museum and tourist attraction, with thousands of people visiting the site every year. Among the Trust's many activities is the reconstruction of many of the machines that helped to break the Axis codes, which you can read more about in the box to the left.

After WWII, Alan Turing went on to advance our knowledge of computers and artificial intelligence even further

HISTORY'S MOST GRUESOME INVENTIONS

FROM BRUTAL TORTURE DEVICES TO BIZARRE MEDICAL TREATMENTS, THESE TERRIFYING CONTRAPTIONS REVEAL A DARKER SIDE OF INNOVATION

From the wheel to the World Wide Web, we have invented some truly ground-breaking things during our time on Earth. Yet throughout history, inventors have also been known to put their skills to use in horrifying ways, creating contraptions that have caused unimaginable suffering.

In the past, if you committed a terrible crime, a punishment much worse than a long prison sentence awaited you. From boiling people alive to sawing them in half, execution methods were often developed to be as cruel as possible. These gruesome events were usually carried out in public to deter others from following in the footsteps of the accused.

Even if you weren't sentenced to death, there were plenty of ghastly implements that could be used to torture you instead. Typically used to extract a confession or information about accomplices, torture was popular in Medieval times, with the screams of victims echoing from castle dungeons across Europe.

War has also inspired a wide selection of horrific innovations. While guns and bombs were designed to kill instantly, chemical weapons could draw out death for several agonising days – thankfully, this form of warfare is now prohibited.

We are also lucky that some medical devices from history are no longer used. Despite being designed with good intentions, many Medieval procedures were truly stomach-churning, making a trip to the doctor quite the ordeal.

So as you drive around in your car and browse the web on your phone, be grateful that the inventions you use aren't gruesome like these...

THE BRAZEN BULL

TURNING THE SCREAMS OF THE DYING INTO THE ROAR OF A BEAST

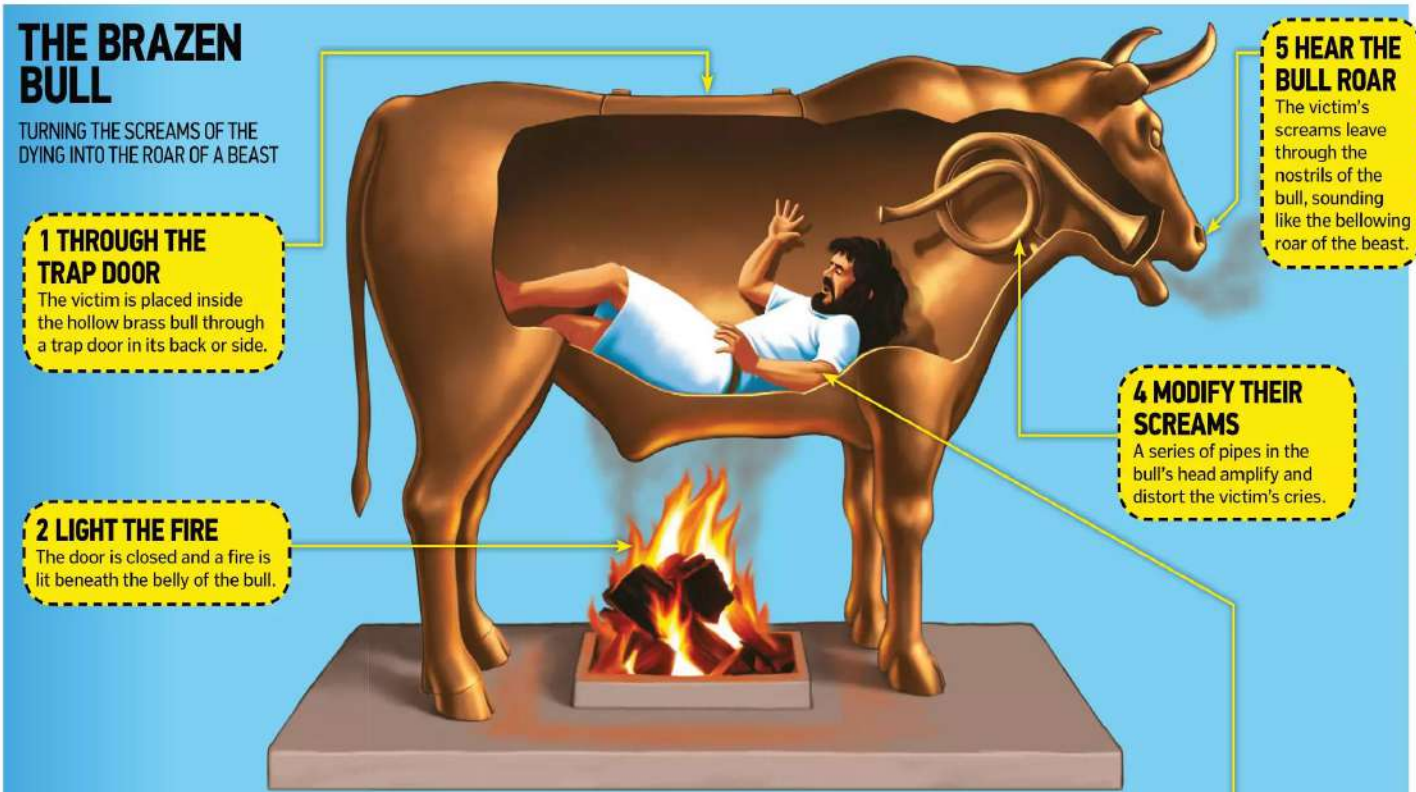


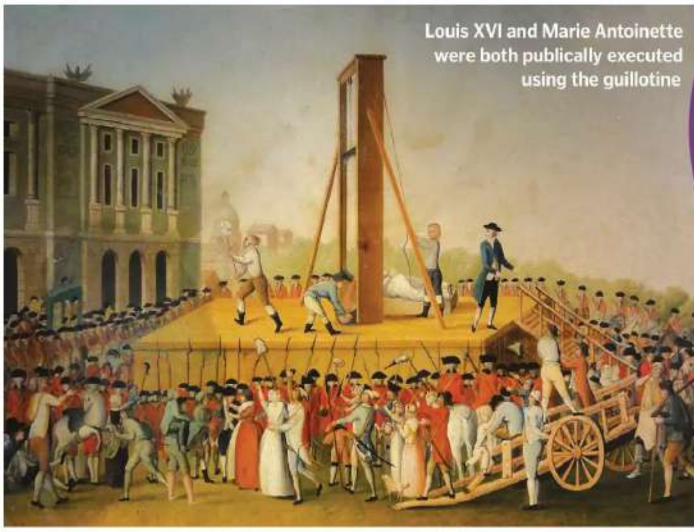
Illustration by Tom Connell / Art Agency

One of the most brutal methods of execution ever created took the form of a hollow bull statue. Invented in Ancient Greece by Perillus, a bronze worker in Athens, it was given as a gift to a cruel tyrant named Phalaris of Agrigentum. As well as roasting criminals alive, the device also doubled as a musical instrument, converting the victim's desperate cries into what Perillus described as "the tenderest, most pathetic, most melodious of bellowings". Distrustful of the inventor's claims, Phalaris ordered Perillus to climb inside and prove the device's musical capabilities himself. However, as soon as he was inside, Phalaris shut the door and lit a fire beneath, causing Perillus to scream for real. However, rather then letting him die at the hands of his own creation, Phalaris had him removed and thrown off a cliff instead.

CRUCIFIXION

Devised over 2,500 years ago as punishment for the most serious crimes, crucifixion would kill victims in a horribly drawn-out and painful way. With their wrists and feet nailed or tightly bound to a cross, and their legs broken by the executioners to speed up death, the victim's weight would be transferred to their arms. This would gradually pull the shoulders and elbows out of their sockets, leaving the chest to bear the weight. Although inhaling would still be possible, exhaling would be difficult and the victim would eventually suffocate due to a lack of oxygen. This excruciating process could take 24 hours.

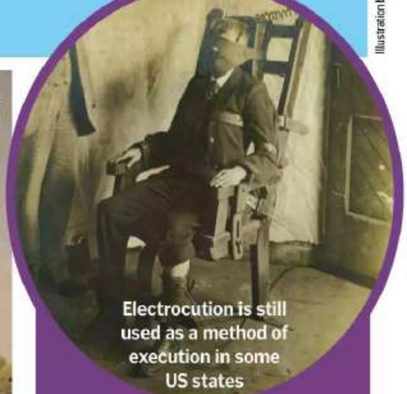
Crucifixion would lead to suffocation and multiple organ failure



Louis XVI and Marie Antoinette were both publically executed using the guillotine

GUILLOTINE

Although beheading methods had already been around for centuries, in 1789 French physician Dr Joseph Guillotin proposed a much more efficient and humane device for decapitation. When the executioner released the rope holding the guillotine's weighted blade in place, it would drop onto the victim's neck, killing them in a fraction of a second. This helped to eliminate the human error that was common with axe and sword beheadings, which sometimes required the executioner to deliver multiple swings to fully remove the head. Although quick, guillotine executions were popular spectator events during the French Revolution and the guillotine operators become national celebrities.



Electrocution is still used as a method of execution in some US states

ELECTRIC CHAIR

Electrocution was introduced as a quicker and supposedly less painful method of execution than hanging in the 1880s. When brought to the electric chair, a person has their head and one calf shaved to reduce resistance to electricity and is strapped in across their waist, arms and legs. A moistened sponge is then placed on their head and an electrode in the shape of a metal skullcap is secured on top. Another electrode is attached to their shaved leg and then the power is switched on. 2,000 volts pass through their body, paralysing the respiratory system and causing cardiac arrest.

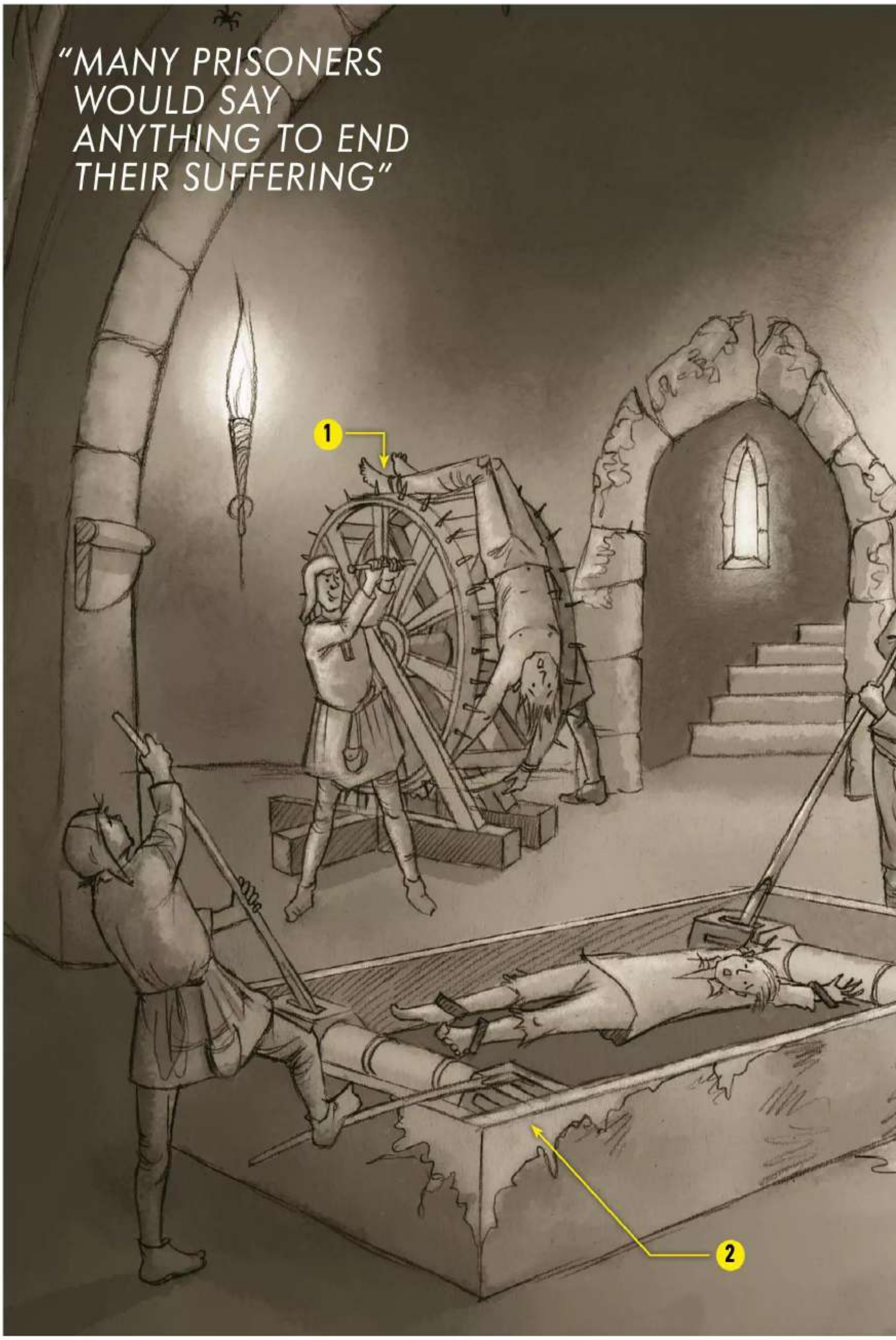
INSIDE A TORTURE CHAMBER

THE TERRIFYING DEVICES THAT INFLICTED INTENSE PAIN

Torture has been used as a method of punishment and interrogation for centuries, with the Ancient Greeks and Romans regularly torturing criminals as part of their justice system. However, by the Middle Ages torture had become particularly prevalent, especially in response to treason. If you had been disloyal to the sovereign and your country, a whole plethora of horrifying torture devices awaited you.

Torture was usually conducted in secret, with most Medieval castles featuring an underground dungeon in which these diabolical deeds took place. A great deal of ingenuity and artistic skill went into developing instruments that would inflict the maximum amount of pain. Often simply threatening to use one on a person was enough to get them to confess, while others would quickly give in after seeing it used on a fellow prisoner. Some torture devices were designed to only inflict pain, but others would result in a slow, drawn-out death that prolonged the suffering until the victim drew their last breath.

However, even if a prisoner was lucky enough to survive the torture, they were usually left severely disfigured and often had to be to be carried to their resulting trial, as they could no longer walk on their own. But from the mid 17th century onwards, torture became much less common as there was much speculation about its effectiveness. Many prisoners would say anything to end their suffering, so it often produced inaccurate information or false confessions. It wasn't until 1948 that the United Nations General Assembly adopted the Universal Declaration of Human Rights, banning the use of torture.



1 BREAKING WHEEL

With the victim's limbs tied to the spokes of this large wooden wheel, it would be slowly revolved. As it spun, the executioner would bludgeon the victim's arms and legs with an iron hammer, shattering their bones one by one. If the victim survived this, they were placed on top of a large pole, so birds could peck at their body until they eventually died of dehydration, which could take several days.

2 THE RACK

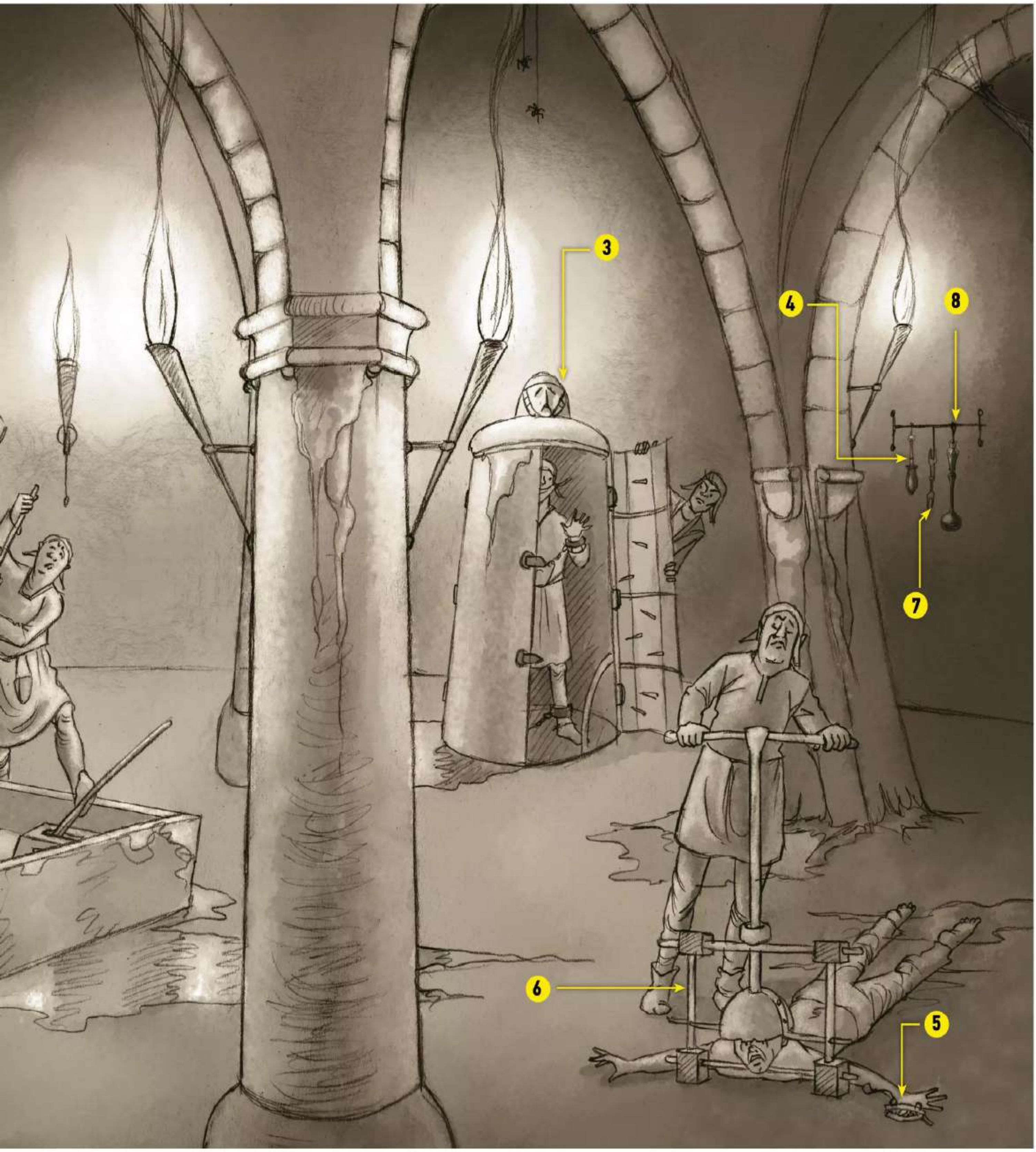
With their hands and feet tied to rollers at each end of the wooden frame, the torture victim would be subjected to intense interrogation. If they failed to confess to their crimes or give up the information the torturer was looking for, a crank would be turned to rotate the rollers. This would pull on the ropes, gradually stretching the victim's body and causing intense pain, eventually dislocating their limbs.

3 IRON MAIDEN

A series of menacing spikes protruded from the interior of this iron chamber. With the victim inside, the door was closed slowly, causing the strategically placed spikes to pierce their body. However, the spikes were not long enough to be instantly fatal. Instead, the victim would be left to slowly bleed to death.

4 CHOKE PEAR

Also known as the 'pear of anguish', this device was inserted into one of the victim's orifices, such as their mouth. When the key or crank was turned, the 'petals' of the pear-shaped end would slowly open up, painfully mutilating the victim's insides, but not causing death.



5 THUMBSCREW

Used as punishment or a method of extracting information, the victim's fingers, thumbs or toes were placed between two horizontal metal bars. When the screw was turned, the two bars were pressed together, crushing the digits inside. Some thumbscrews even featured metal spikes on the bars to increase the pain.

6 HEAD CRUSHER

With the victim's chin placed over the bottom bar and their head beneath the metal cap, the executioner would slowly turn the screw to bring the two together, only stopping if the victim gave the right answers. As the victim's head was crushed, their teeth would shatter into their jaw and their eyes would pop out from their sockets.

7 HERETIC'S FORK

Usually reserved for blasphemers, this metal rod with two prongs at either end was attached to a leather strap around the victim's neck. One end would pierce their chin, while the other dug into their sternum, causing immense pain if they attempted to move their jaw or neck, making it more or less impossible to talk.

8 LEAD SPRINKLER

Deceptively designed to look like a holy water sprinkler, this device was actually filled with molten lead, acid or boiling hot oil or water. The long handle was shaken to shower the victim's body with the substance inside. This caused horrific burns and was potentially lethal.

MISERABLE MEDICINE

THE MEDICAL PRACTICES THAT DID MORE HARM THAN GOOD

Nowadays, when you're feeling unwell you can visit a clean hospital and receive tried and tested treatments from a doctor with years of medical training. We often take this modern medicine for granted, but our ancestors throughout history were not quite so lucky when it came to health care. In Medieval England, for example, poor hygiene and filthy living conditions meant that disease was very common.

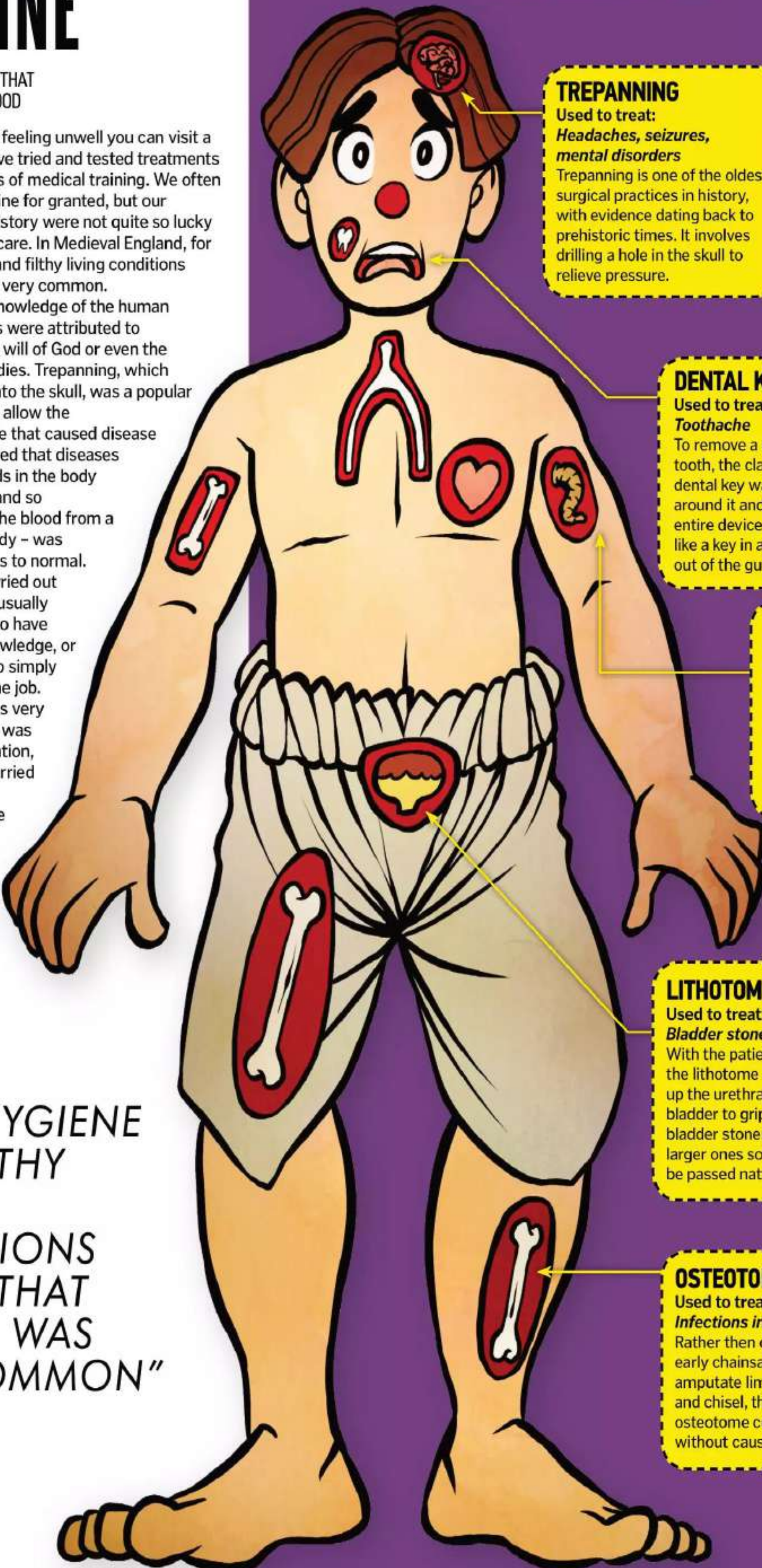
However, with little knowledge of the human anatomy, many illnesses were attributed to witchcraft, demons, the will of God or even the positions of celestial bodies. Trepanning, which involves drilling a hole into the skull, was a popular treatment prescribed to allow the evil spirits trapped inside that caused disease to escape. Others believed that diseases were caused by the fluids in the body becoming unbalanced, and so bloodletting – draining the blood from a particular part of the body – was thought to restore things to normal.

The 'doctors' who carried out these procedures were usually monks, as they tended to have some basic medical knowledge, or barbers or butchers who simply had the right tools for the job. The equipment used was very rarely sterilised, as little was known about contamination, and procedures were carried out with no form of anaesthesia to numb the pain. It's no wonder that people would put off seeking treatment for as long as possible!

"POOR HYGIENE AND FILTHY LIVING CONDITIONS MEANT THAT DISEASE WAS VERY COMMON"

TERRIFYING TREATMENTS

HORRIFYING MEDICAL INSTRUMENTS AND PROCEDURES FROM THE PAST



TREPANNING

Used to treat:
Headaches, seizures, mental disorders

Trepanning is one of the oldest surgical practices in history, with evidence dating back to prehistoric times. It involves drilling a hole in the skull to relieve pressure.

DENTAL KEY

Used to treat:
Toothache

To remove a damaged tooth, the claw end of the dental key was clamped around it and then the entire device was turned like a key in a lock to lift it out of the gum.

ARTIFICIAL LEECH

Used to treat:
Various infections and diseases

Used for bloodletting a popular treatment for a wide range of medical conditions, this device mimicked the action of reel leeches, with rotating blades that cut into the skin whilst a vacuum in the cylinder sucked out the blood.

LITHOTOME

Used to treat:
Bladder stones

With the patient still awake, the lithotome was inserted up the urethra and into the bladder to grip onto smaller bladder stones or cut up larger ones so they could be passed naturally.

OSTEOTOME

Used to treat:
Infections in the arms or legs

Rather then cutting down trees, this early chainsaw was actually used to amputate limbs. Unlike a hammer and chisel, the hand-cranked osteotome could cut through bone without causing it to splinter.

WEAPONS OF WAR

HOW THE CHEMICAL ARMS RACE CHANGED THE FACE OF CONFLICT

CHEMICAL WEAPONS

On 22 April 1915, Germany shocked the world by launching the first large-scale gas attack in war. After waiting several weeks for the wind to blow in the right direction, German soldiers released clouds of chlorine gas near the enemy trenches in Ypres, suffocating the unprepared Allied troops. Although The Hague Convention of 1899 prohibited the use of poisonous weapons, Germany justified its actions by claiming that France had already broken the ban by deploying tear gas grenades in 1914. The chlorine gas attack kick-started a chemical arms race and by the end of World War I, around 50 different chemicals had been used on the battlefield. The most prevalent were chlorine, phosgene and mustard gas, which would result in slow and painful deaths if soldiers were exposed to large enough quantities. Eventually, gas masks were developed for protection, but chemicals such as mustard gas could still cause horrific blisters if they came into contact with the skin. Among the most devastating chemical weapons are nerve agents, such as sarin, which attack the nervous system. Even small concentrations can be lethal, killing in mere minutes.

Cl_2

CHLORINE

Appearing as a pale green cloud with a strong bleach-like odour, chlorine gas reacts with water in the lungs to form hydrochloric acid. This damages the lung tissue, causing coughing, vomiting and eventually death.

$COCl_2$

PHOSGENE

This colourless gas with a musty odour reacts with proteins in the alveoli, tiny air sacs found in the lungs. This leads to fluid in the lungs and eventually suffocation, but the symptoms can take up to 48 hours to manifest.

$C_4H_8Cl_2S$

MUSTARD GAS

With the odour of garlic, horseradish or sulphur, yellow-brown clouds of mustard gas cause chemical burns on the skin, eyes and respiratory tract, leading to large blisters, temporary blindness and shortness of breath.

$C_4H_{10}FO_2P$

SARIN

Colourless, tasteless and odourless, this gas blocks normal communication between nerves. The nerve signals become stuck 'on', and muscles are unable to relax. This can lead to spasms, paralysis and asphyxiation.

THE GENEVA PROTOCOL

By the end of World War I, over 125,000 tons of poison gas had been deployed in battle. Although it was only responsible for less than one per cent of the war's total fatalities, the psychological terror it had inflicted on soldiers was immense. On 17 June 1925, seven years after the war had ended, the Geneva Protocol was introduced, prohibiting the use of chemical and biological weapons. 138 states have now signed the treaty.

38 states originally signed the Geneva Protocol to ban the use of chemical weapons

NAPALM

Napalm is a flammable liquid with a gel-like consistency, allowing it to stick to surfaces easily. In a bomb, it is combined with gasoline or jet fuel to explode upon impact, capable of burning at more than 2,760 degrees Celsius. Even the slightest contact with skin can result in severe burns and it can also cause death by asphyxiation. When ignited, napalm generates carbon monoxide and removes oxygen from the air, suffocating those in the vicinity.

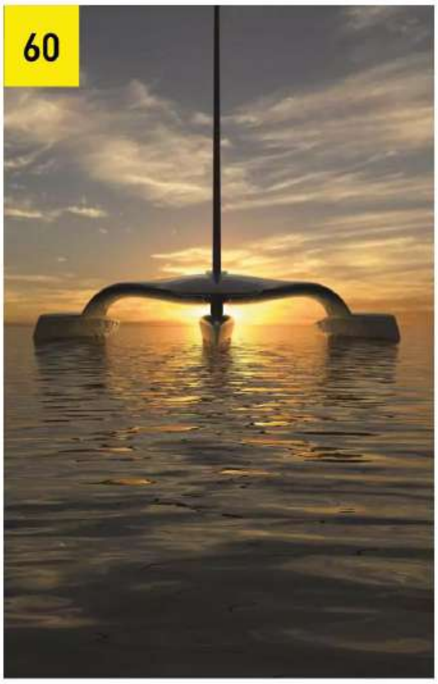
Napalm fires combust oxygen in the air, turning carbon dioxide into carbon monoxide

GREEK FIRE

Developed by the Byzantine Greeks in the 7th century, Greek fire was a flammable liquid that could burn on water, making it particularly effective for naval warfare. This liquid fire was sprayed at the enemy using early flamethrower devices, or thrown in primitive hand grenades, creating a raging fire that could only be extinguished with sand, vinegar or urine. The true ingredients are a mystery, but scientists believe it could have contained petroleum, sulphur and pine tar.

Greek fire was the napalm of its day, but its ingredients are a mystery

TRANSPORT



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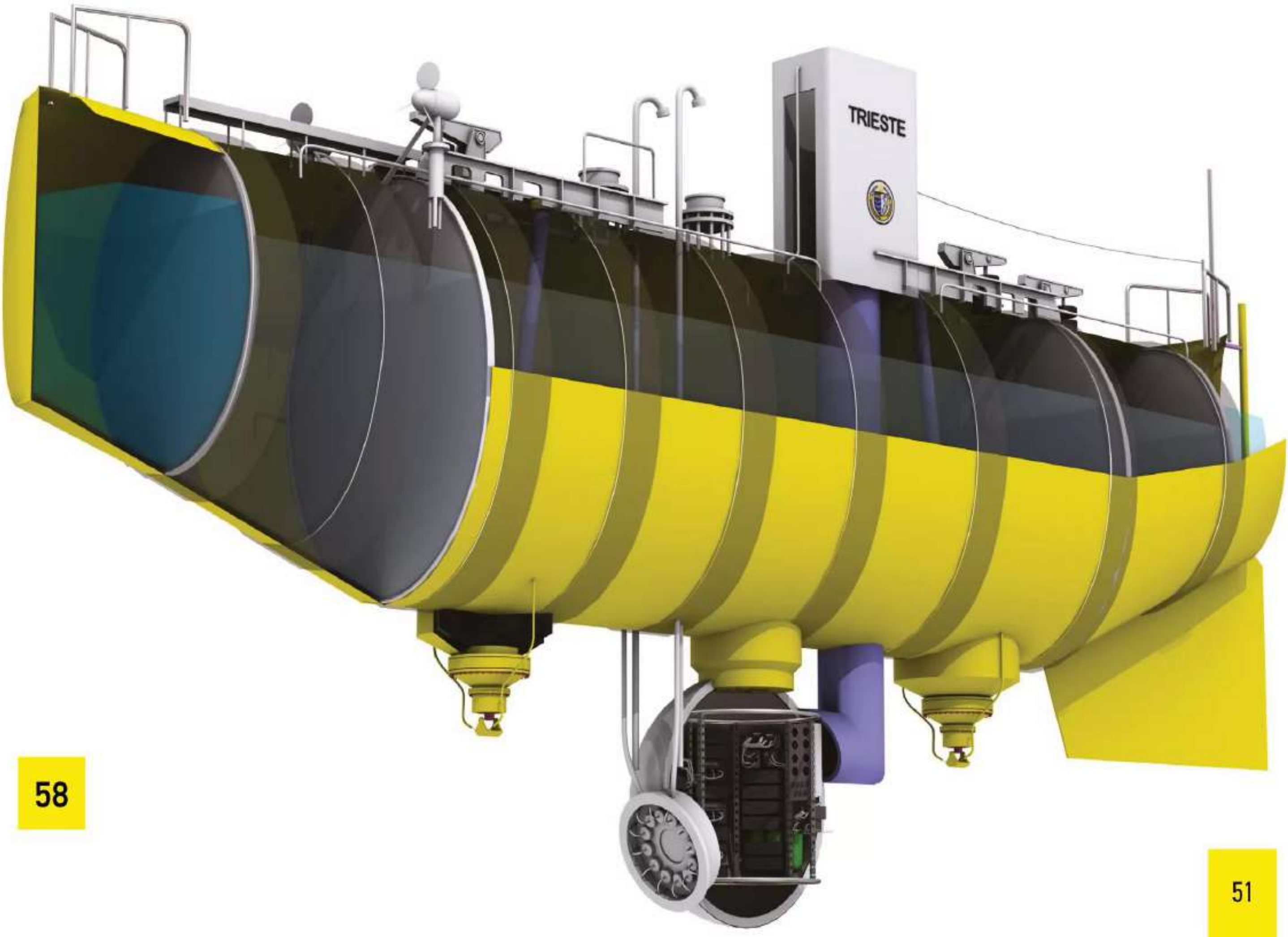

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THE NEWCOMEN STEAM ENGINE

HOW DID THIS GROUNDBREAKING ENGINE WORK AND HOW DID IT HELP BRING ABOUT THE INDUSTRIAL REVOLUTION?

The Newcomen steam engine – which was named after its inventor Thomas Newcomen – was the world's first practical device designed to harness the power of steam for mechanical work. The first one was built in 1712.

The machine worked by combining the pre-existing technologies of a steam cylinder with a steam-driven piston to raise and lower a pump rod via a balance beam. For a complete mechanical breakdown of the process, see the central diagram. The result of this combination enabled Newcomen to create a lifting engine that by simply burning coal could continuously pump large quantities of water out of wells, mines and other reservoirs without the need of manual labour (pumps were usually driven by horse prior to this invention).

Indeed, the relative simplicity of the device and cost-effectiveness when compared to maintaining a stable of animals, in combination with the rapid expansion of England's industry in the early 18th century, saw the machine surge in popularity, with Newcomen engines installed not just in England, Scotland and Wales but also mainland Europe. In fact, by the mid 18th century – only 40 or so years after Newcomen invented his engine – there were more than 100 systems in operation. For this reason, and in light of the massive role the steam engine would play in developing British industry, today Newcomen's game-changing invention is seen as one of the primary catalysts of the Industrial Revolution.

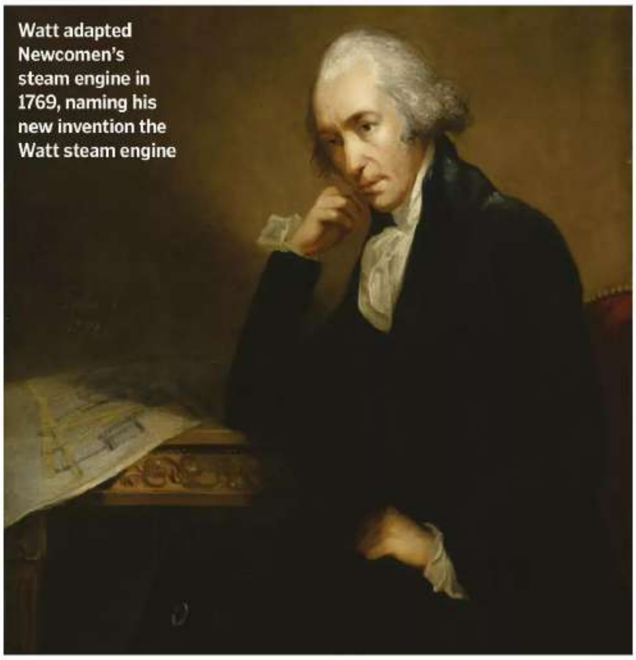
Not surprisingly, however, the engine was incredibly crude by modern standards, and indeed those reached by the latter end of the 18th century. In fact, it suffered from a fundamental flaw that was only addressed in 1769. This was that by directly cooling the engine's piston cylinder for each steam cycle, much of the boiler's generated steam was wasted bringing it back up to temperature in the next. This problem was exacerbated by the fact that the larger the Newcomen engine, the larger the cylinder, and as a direct consequence, the more steam was needed to reheat the cylinder. This led to ever-greater quantities of steam to be wasted in the heat-up process and so ever-more coal was burnt to facilitate this.

Regardless of this flaw, the Newcomen engine's ability to transform the power of steam into kinetic energy and mechanical work was a huge milestone in human engineering that played a key role in shaping British industry at this pivotal point in the country's history.

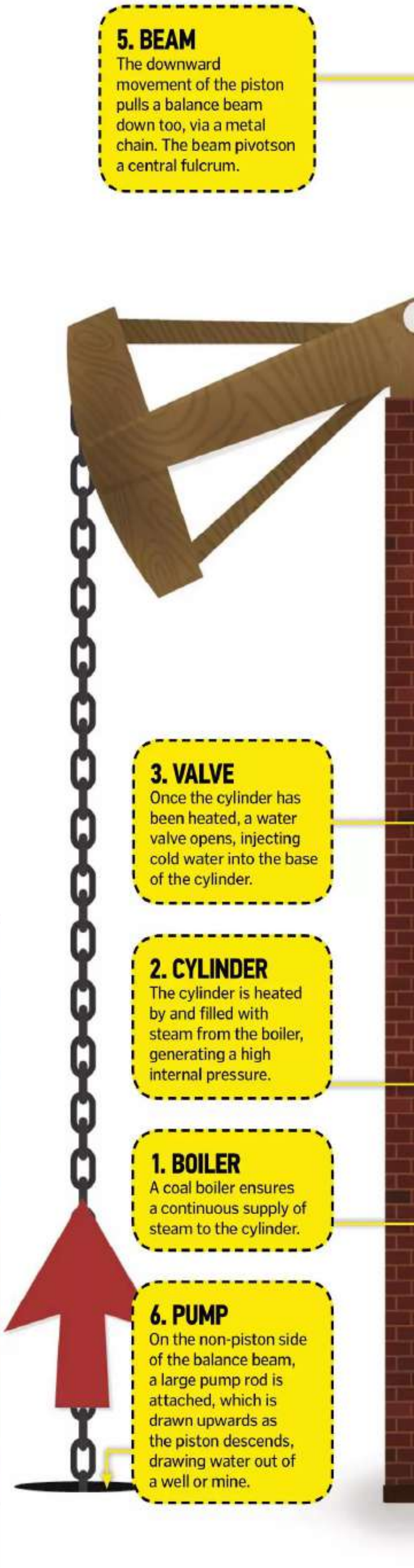
WHAT DID WATT DO?

The main problem with Newcomen's steam engine was that it was incredibly costly to operate. This was because each time its central cylinder was cooled to create a vacuum, the cylinder walls remained cold as the next wave of steam was fed in, condensing a proportion of it immediately. This reheating of the cylinder wasted a large quantity of steam, dramatically increasing coal consumption.

This problem was solved in 1769 by Scottish engineer James Watt, who realised, while repairing an old Newcomen engine at Glasgow University, that if condensation took place in a separate container attached to the steam cylinder by pipe, the latter could remain hot at all times. Watt proceeded to patent his new steam engine and, despite it being heavily based on Thomas Newcomen's original, avoided paying any royalties by rigorously defending a number of lawsuits personally.

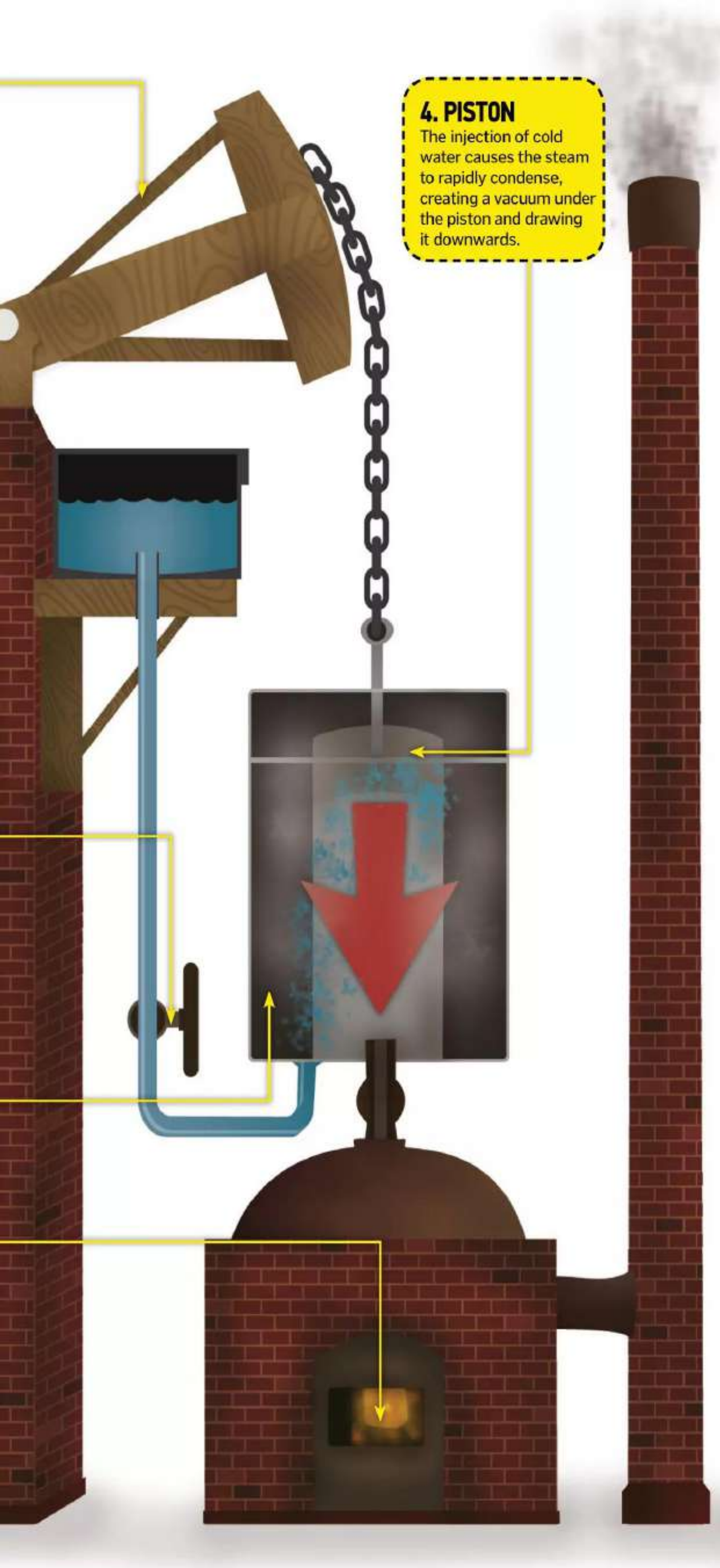


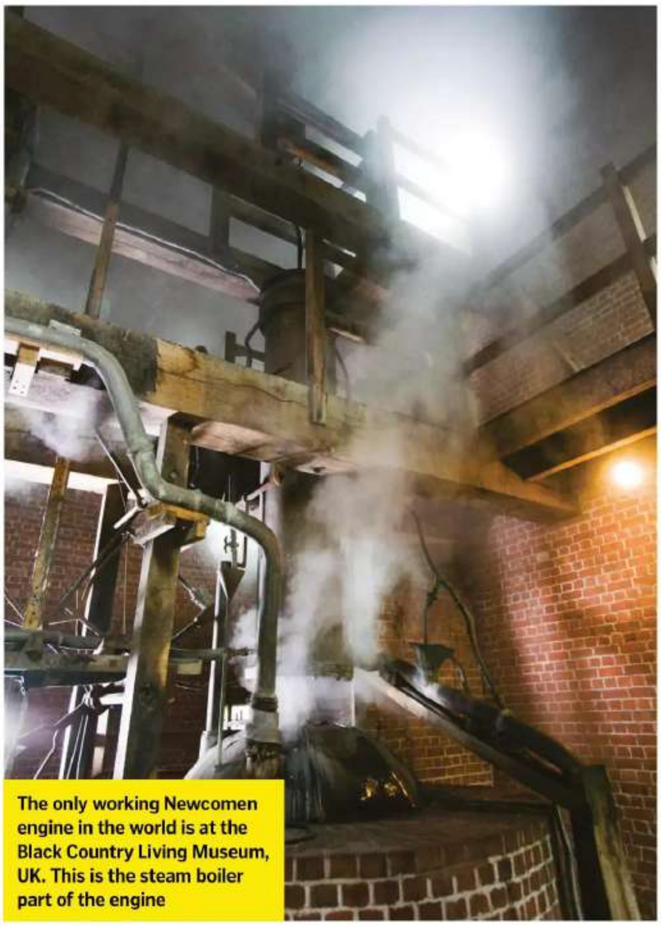
Watt adapted Newcomen's steam engine in 1769, naming his new invention the Watt steam engine



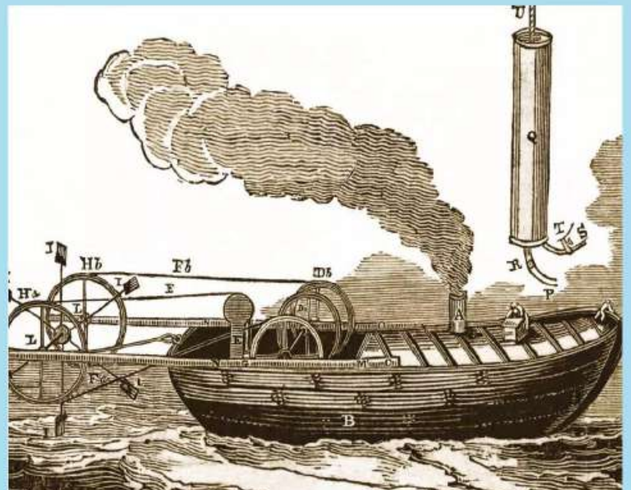
HOW DID THE NEWCOMEN ENGINE GENERATE POWER?

FOLLOW OUR STEP-BY-STEP GUIDE TO THE WORKINGS OF THIS REVOLUTIONARY PIECE OF MACHINERY





The only working Newcomen engine in the world is at the Black Country Living Museum, UK. This is the steam boiler part of the engine



A depiction of Hulls' steamboat from *Mechanics' Magazine*, October 1823

HULLS' NEWCOMEN STEAMBOAT

Since their inception, steam engines were increasingly seen as a future means of vehicle propulsion. A good example can be seen in English inventor Jonathan Hulls' design of a steamboat, a small vessel powered by a Newcomen engine. Unfortunately, despite being granted a patent for his steamboat in 1736, it was never built as the inefficient and cumbersome engine was thought infeasible. Interestingly, it wasn't until 1774 that a working steamboat was successfully piloted, with the Marquis d'Abbans, Claude-François-Dorothée de Jouffroy, both building and captaining the Palmipède (or 'Webfoot') vessel in Lyon, France.

RACK-AND-PINION RAILWAYS

HOW DID THESE UNIQUE TRANSIT SYSTEMS HELP HEFTY LOCOMOTIVES SCALE STEEPER MOUNTAIN SLOPES THAN EVER BEFORE?

A rack-and-pinion railway (also known as a cog railway) was one that employed a toothed track. The addition of the toothed rail – which was usually located centrally between the two running rails – enabled locomotives to traverse steep gradients of over 7 per cent, which remains to this day the maximum limit for standard adhesion-based railways.

Core to the operation of each rack-and-pinion system was the engagement of the locomotive's circular gears onto the linear rack. The rack and pinion therefore was essentially a means of converting the rotational energy generated by the train's powerplant into linear motion on the rack. As both the rack-and-pinion gears had teeth, the system also acted as an additional form of adhesion to the track, with the inter-meshing teeth holding the vehicle in place when not in motion.

Due to the primary form of power traditionally being steam, for rack-and-pinion systems to work the trains needed to be considerably adjusted. This modification stretched from the undercarriage of the train (so pinions could be installed) to the tilting of its boiler, cab and superstructure.

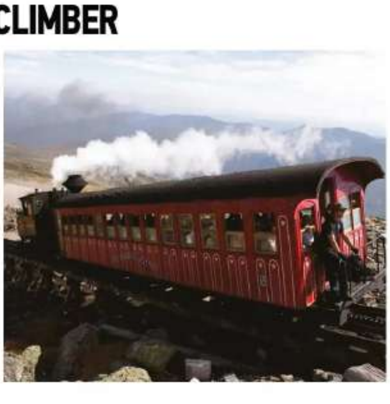
Tilting was necessary as steam engine boilers require water to cover the boiler tubes and firebox at all times to maintain stability – something that is nigh-on impossible to achieve if the train isn't level. As such, cog railway locomotives would lean in towards the track to counter the terrain's gradient.

Today, while rare, rack-and-pinion systems are still in operation worldwide, albeit with a mix of steam engines and diesel/electric locomotives. One of the most famous is the Mount Washington Cog Railway.

A rack-and-pinion railway built with a Strub system in rural Italy, 1920

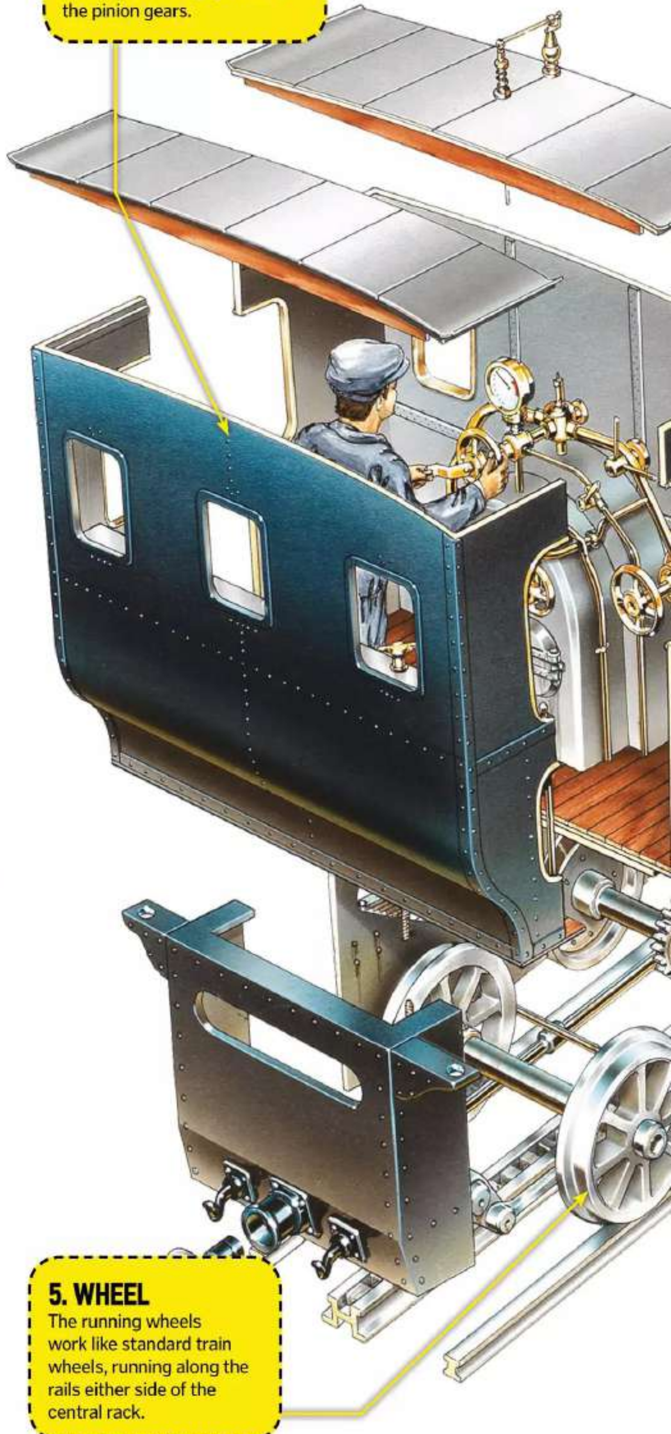
A MECHANICAL MOUNTAIN CLIMBER

The Mount Washington Cog Railway in New Hampshire, US, was the first rack-and-pinion railway used to climb a mountain. Completed by Sylvester Marsh in 1869, the system is the second-steepest rack railway in the world, with a top gradient of 37.4 per cent. The railway runs 4.8 kilometres up Mount Washington's western slope, beginning at 820 metres above sea level and culminating just short of the peak at 1,917 metres. The locomotive goes up at 4.5 kilometres per hour and descends at 7.4 kilometres per hour. Despite being built 144 years ago, this cog railway is still fully operational.



RACK AND ROLL

UNDERSTAND THE ANATOMY OF A RACK-AND-PINION LOCOMOTIVE WITH OUR CUTAWAY ILLUSTRATION



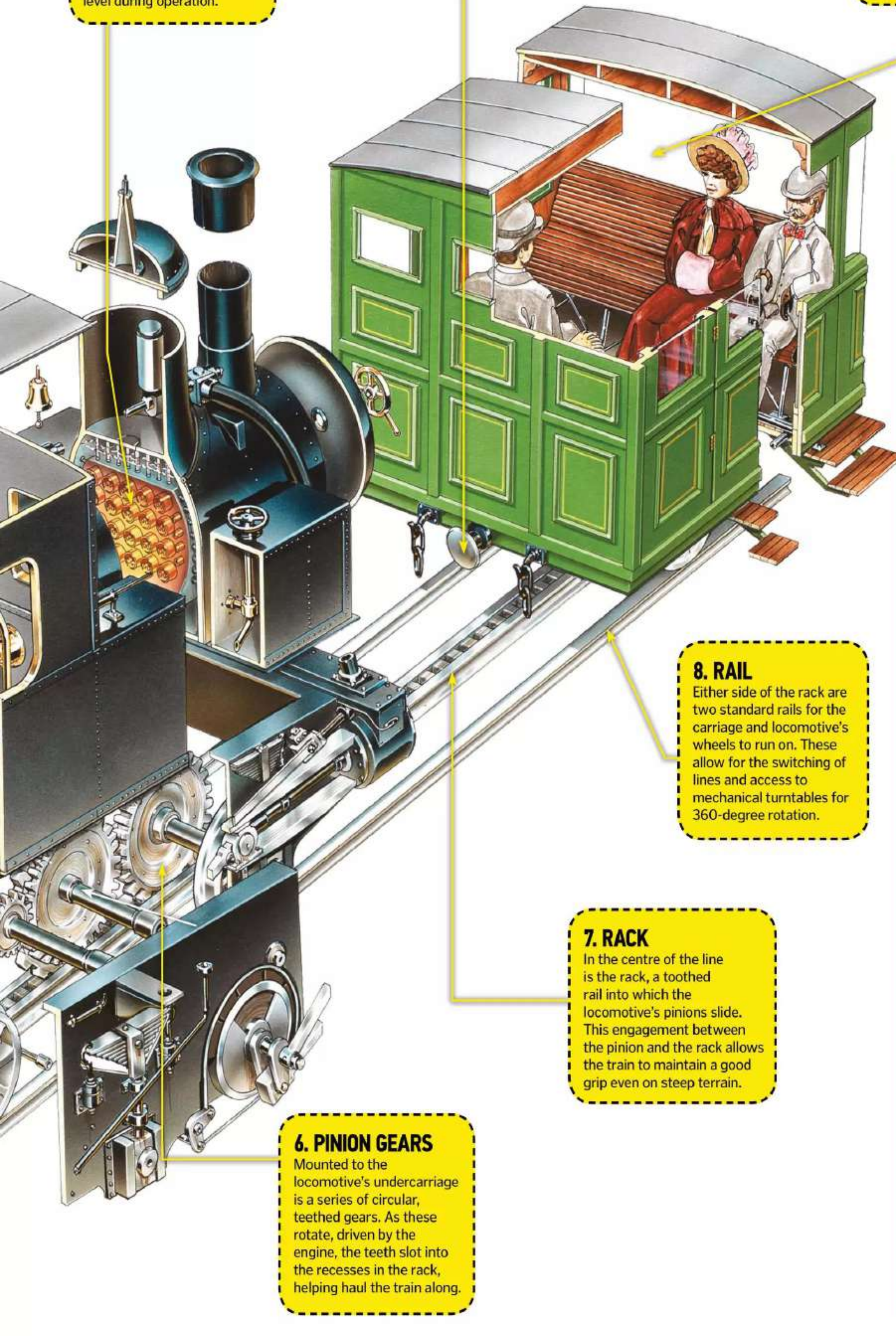
1. CABIN
To the rear of the engine and carriage is the cabin. From here the driver controls the steam boiler and the engagement of the pinion gears.

5. WHEEL
The running wheels work like standard train wheels, running along the rails either side of the central rack.

2. ENGINE
Older cog railways would use steam engines to provide the power to drive the pinion gears. As with the cab, the engine is tilted forward so it's level during operation.

3. BUFFER
Unlike standard adhesion trains, rack-and-pinion systems don't tend to attach the carriage to the locomotive with a linkage. Instead, the carriage is simply pushed with the locomotive's buffers.

4. CARRIAGE
Passengers sit in a covered wooden carriage. Due to the slow nature of the system, larger-than-standard windows are often installed that offer panoramic views.



8. RAIL
Either side of the rack are two standard rails for the carriage and locomotive's wheels to run on. These allow for the switching of lines and access to mechanical turntables for 360-degree rotation.

7. RACK
In the centre of the line is the rack, a toothed rail into which the locomotive's pinions slide. This engagement between the pinion and the rack allows the train to maintain a good grip even on steep terrain.

6. PINION GEARS
Mounted to the locomotive's undercarriage is a series of circular, teethed gears. As these rotate, driven by the engine, the teeth slot into the recesses in the rack, helping haul the train along.

COG RAILWAY EVOLUTION

1 MARSH
Made famous by the Mount Washington Cog Railway, the Marsh system – invented by Sylvester Marsh in 1861 – used the locomotive's gear teeth like rollers, arranged in rungs between two 'L'-shaped wrought-iron rails.

2 RIGGENBACH
The 1863-made system created by inventor Niklaus Riggenbach used a ladder rack made from steel plates connected by regularly spaced rods. While effective, the fixed ladder rack was fairly complicated and expensive to build, so very few examples survive today.

3 ABT
Carl Roman Abt improved the Riggenbach system in 1882 by using multiple solid bars with vertical teeth machined into them that were mounted centrally between the pinions the rails. This ensured the pinions on the wheels were in constant contact with the rack.

4 LOCHER
Eduard Locher's system, designed in 1889, had gear teeth cut into the sides of the rails rather than the top, which were engaged by two cog wheels on the locomotive. This new system could work on steeper track gradients than anything prior.

5 STRUB
Invented by Emil Strub in 1896, the Strub system utilised a rolled flat-bottom rail with rack teeth machined into the head 100 millimetres (four inches) apart. The safety jaws installed on the locomotive gripped the underside of the head in order to prevent dangerous derailments.

THE AUTOMOBILE

FROM STEAM-POWERED CART TO ECO-FRIENDLY HYBRID, TRACK THE DEVELOPMENT OF THE MOTOR CAR

Born out of the Industrial Revolution, the automobile, for good or bad, is now the most popular form of transport on Earth, granting individuals the ability to travel a wide range of distances with unparalleled freedom. Today, the majority of cars are powered by internal combustion engines fed by fossil fuels – a factor that has led to new electric and hydrogen vehicles to be pioneered in the past decade. Today's cars also feature a variety of complicated mechanical and electronic systems designed to maximise performance and enhance the driver's experience and safety in the vehicle. However, the road to this motoring nirvana has been a long and, at times, painful process, with the evolution of the car leaving a number of technologies, products and companies by the roadside. How It Works charts the rise of the modern car from its humble beginnings through to its powerful and versatile modern incarnations, highlighting successes and failures, as well as the scandals and controversies that have shaped the motoring industry.

THE FIRST CARS

STEAM POWER

1769
Fardier à vapeur
Nicolas-Joseph Cugnot invented his fardier à vapeur ('steam cart') in 1769. It could carry four tons over a 4.8-mile stretch and was powered by a front-mounted steam boiler, but had a stately top speed of just 3.6km/h (2.25mph) and it was very unstable.

GAS POWER

1870
Marcus I
Vienna inventor Siegfried Marcus strapped a liquid-fuelled combustion engine to a simple handcart. The resulting automobile became known as 'the first Marcus car', and it granted Marcus the accolade of being first man to propel a vehicle by gasoline.

BENCHMARK

1886
Benz Patent-Motorwagen
Considered the first true motor car, this was designed by Karl Benz. It featured three wheels, a steel chassis, solid rubber tyres and a single-cylinder four-stroke petrol engine that produced $^2/_3$hp at 250rpm and a top speed of 16km/h (10mph).

INTERNATIONAL

1891
Systeme Panhard
This breakthrough design featured four wheels, a front-mounted engine, rear-wheel drive and a sliding gear transmission. The vehicle sold for 3,500 francs and proceeded to sell well worldwide as well as win numerous races through the 1890s.

ELECTRIC POWER

1899
La Jamais Contente
Translating as 'The Never Satisfied', this was the first ever vehicle to surpass 100km/h (62mph). It was a pure electric vehicle, based on a light alloy, torpedo-shaped chassis. Until 1910, the electric car market was promising and vibrant.

MASS PRODUCTION

1908
Ford Model T
The invention of the production line by Henry Ford allowed more than 15 million Model Ts to be produced over a 19-year period. Due to its good functionality, value and simple design, it is now considered the most influential car of the 20th century.

THOROUGHBRED

1910
Bugatti Type 13
The first production car from Bugatti, it created the concept of the 'thoroughbred' within the car industry, something taken directly from Ettore Bugatti's philosophy that cars should be built on the principles of agility, speed and spirit alone.

CHEAP PRODUCTION

1922
Austin 7
The Austin 7 dominated the British market throughout the 1920s thanks to its simple and cheap design. Over 290,000 were sold during its 17-year production run, and it is remembered for being the first car to feature the now standard control layout.

FORMULA ONE

FORMULA ONE

1950
Formula One
The pinnacle of motorsport, Formula One features the crème de la crème of motoring engineering and mechanics. Since its inception in 1950, it has taken automobiles to an entirely different level, allowing drivers to accelerate quicker, brake later and turn more sharply than standard road vehicles. Today, the sport attracts a global television audience of over 500 million people.

FANTASTIC FLOP!

1958 – Edsel
The Ford Edsel was supposed to reinvent the automobile, but despite all the hype – including a TV special – it was a huge flop. The Edsel project lost Ford $350 million (roughly $2.5bn in today's money) and was dropped after just two years.

1780s | 1880s | 1890s | 1900s | 1910s | 1920s

1951

1985

2011

HIGH-END LUXURY

1936
Rolls-Royce Phantom III

The height of luxury, the Phantom III offered a twin-ignition system, independent front and rear suspension, bespoke interior, a seven-litre V12 engine and a four-speed manual transmission with synchromesh technology.

1999 Ferrari 360
SUPERCARS

Officially the bestselling Ferrari of all time, it has sold over 17,000 coupes and convertibles world wide. Based on a 3.6-litre V8 engine, the 360 boasted a 0-60mph time of 4.3 seconds and top speed of 186mph. Used 360s currently sell from $40,000, earning this model the title of 'best everyday supercar'.

1999

HI-TECH LEADER

2011
Mercedes-Benz E-Class

From passenger safety cells, through climate control, to driver warning systems, the E-Class is one of the most advanced, complex and safe cars on the market today.

GRAND TOURER

1961
Jaguar E-Type

The E-Type epitomised the growing 'Grand Tourer' market in the 1960s and 1970s. It was powered by a 3.8-litre, six-cylinder engine, could do 0-60mph in 7.1 secs and had a top speed of 149mph.

WARNING!

1981 Bolt-ing about

GM recalls 5.8 million cars due to suspension bolts coming loose, causing a lack of steering control.

FANTASTIC FLOP!

1981
DeLorean DMC-12

Immortalised in the *Back to the Future* films, in reality the DMC-12 was a commercial flop. Engineering problems, budget overruns and company founder John DeLorean being arrested for drug trafficking led to the firm going bankrupt.

SUPER CARS

FANTASTIC FLOP!

1980 – Vector W2

The W2 holds the official record for the longest testing period for a concept car. It spent eight years in development limbo, with not one production car ever made. Still, a successor named the W8 did get made in the early 1990s.

WARNING!

2009 Pedal to the metal

Toyota Motors had to recall 3.8 million cars, trucks and SUVs due to sticking accelerator pedals.

ECONOMY

1948
Morris Minor

Due to the Minor being incredibly cheap and in production for 23 years, over 1.3 million were produced and sold all over the world. While much loved, the Minor is also remembered for its poor safety features.

WARNING!

1971 Pinto petroleum

The Ford Pinto often exploded in rear-end collisions due to poor fuel-tank reinforcement.

WARNING!

2000 Blame game

SUV maker Ford and tyre firm Firestone blamed each other after hundreds of deaths due to car rollover accidents.

WARNING!

1965 Corvair scare

The Chevrolet Corvair was so unsafe that US political activist Ralph Nader wrote a book mentioning it, called *Unsafe at Any Speed*.

THE FUTURE

PART SHARING

1999
Ford Focus

The Ford Focus has been a huge cross-continent sales hit, highlighting a trend for cross-market releases and the rise of the 'world car' production philosophy.

POWER SALOON

1975
BMW 3-Series

Officially BMW's best ever selling car, the 3-Series' pairing of performance with fuel economy – pioneered by its diesel variants especially – has led to millions being sold.

WARNING!

1995 Buckle up

Honda was forced to recall 3.7 million cars due to problems with seat belts trapping passengers or not working at all.

2001

2001 Toyota Prius
ECO FREINDLY

One of the most successful alternative-energy-fuelled cars ever made, the Toyota Prius took hybrid engines mainstream, selling 2 million units within ten years. Offering fuel economy rates of up to 72.4mpg, as well as a chassis constructed from plant-derived ecological bioplastics, the Prius is pioneering the current green car movement.

930s | 1940s | 1950s | 1960s | 1980s | 1990s | 2000s

BATHYSCAPHE TRIESTE

A REAL-LIFE NAUTILUS, THE BATHYSCAPHE TRIESTE EXPLORED THE DEEPEST PARTS OF EARTH'S OCEANS, REMAINING TO THIS DAY THE ONLY MANNED VEHICLE TO HAVE REACHED THE BOTTOM OF THE MARIANA TRENCH IN THE PACIFIC

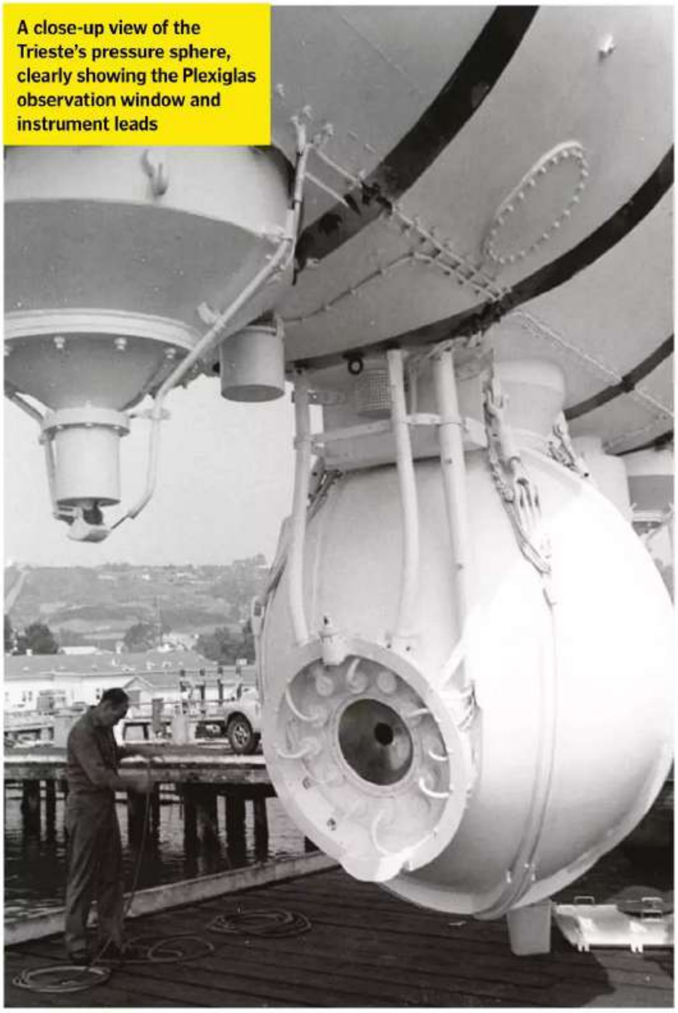
After passing 9,000 metres (30,000 feet), one of the Plexiglas windows cracked. Over 1,000 atmospheres – a pressure over six tons per square inch – relentlessly bore down upon the Bathyscaphe Trieste. The hull shook violently, threatening to collapse under the mighty strain. If fractured on even a microscopic scale, the weight of the Earth's deepest ocean would rip the vessel in two, triggering explosive decompression and instantly killing both oceanographer Jacques Piccard and pilot Lieutenant Don Walsh of the US Navy. 23 January 1960, however, was not their day to die. The men had still not reached the bottom of the Mariana Trench's Challenger Deep; the structure had to hold – there was no plan B.

Descending further into the black void, completely cut off from the outside world – the sonar/hydrophone communications system had packed up hours ago – the Trieste continued to dump iron pellets into its ballast system. After all, you don't descend vertically nine kilometres (nearly six miles) beneath the surface of the ocean only to quit so close to your goal. Then finally, out of nowhere and after four hours and 48 minutes within a two-metre (seven-foot) pressurised sphere, Piccard, Walsh and the Trieste touched down. Clouds of diatomaceous ooze (made of the skeletons of dead sea-creatures) diffused from the seabed on contact, filling the surrounding water with a liquidated organic haze.

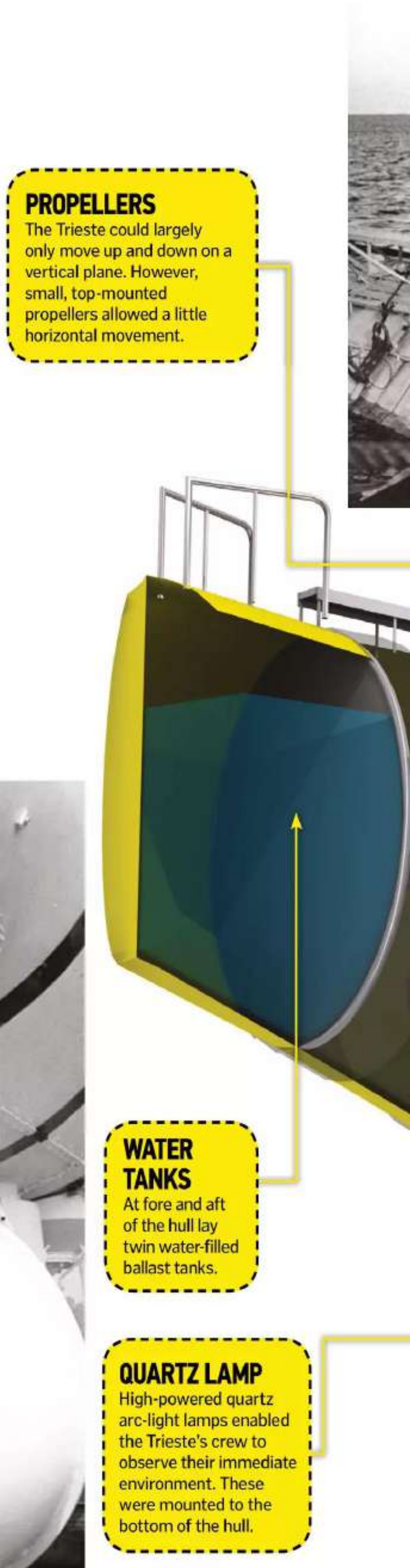
Half an hour later, after periodically observing this alien environment with high-powered quartz arc-light lamps – periodically as when activated they caused the water to violently boil – and discovering a multitude of life including a white flatfish, several shrimp and jellyfish, Piccard initiated the Trieste's ascent. The vessel had held, but at a depth of 10,916 metres (35,814 feet) the temperature of the pressure sphere was dropping continuously (the minimum recorded was just seven degrees Celsius/45 degrees Fahrenheit); if they were not careful, there would be no return. Three hours and 15 minutes later, the Trieste re-emerged into the daylight and human civilisation. The vessel and its crew had been to a world only envisioned in fiction and returned with field-changing information.

Key to the data gathered was establishing the existence of life at the bottom of Earth's deepest ocean. This revealed that not only were there creatures impervious to extreme atmospheric pressures, but also that water at this depth wasn't stagnant. This was a clear indication that ocean currents penetrated even these extreme depths, so they should not be used as a dumping ground for radioactive waste. Unfortunately, despite this first-hand evidence, dumping of this kind still continues throughout large parts of the world to this day.

Today the legacy of the Trieste is being built upon, with numerous programmes currently underway that are focused on designing new vehicles to return to this uncharted territory. The most high profile of these is Richard Branson's Virgin Oceanic, although this was put on hold in late 2014 until more suitable technologies are developed.

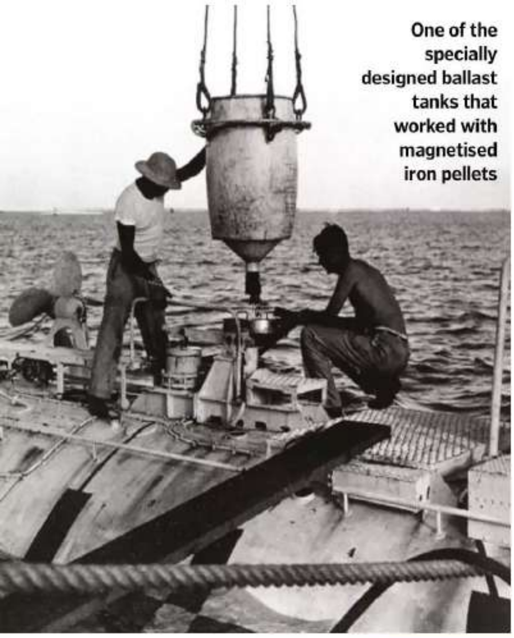


A close-up view of the Trieste's pressure sphere, clearly showing the Plexiglas observation window and instrument leads



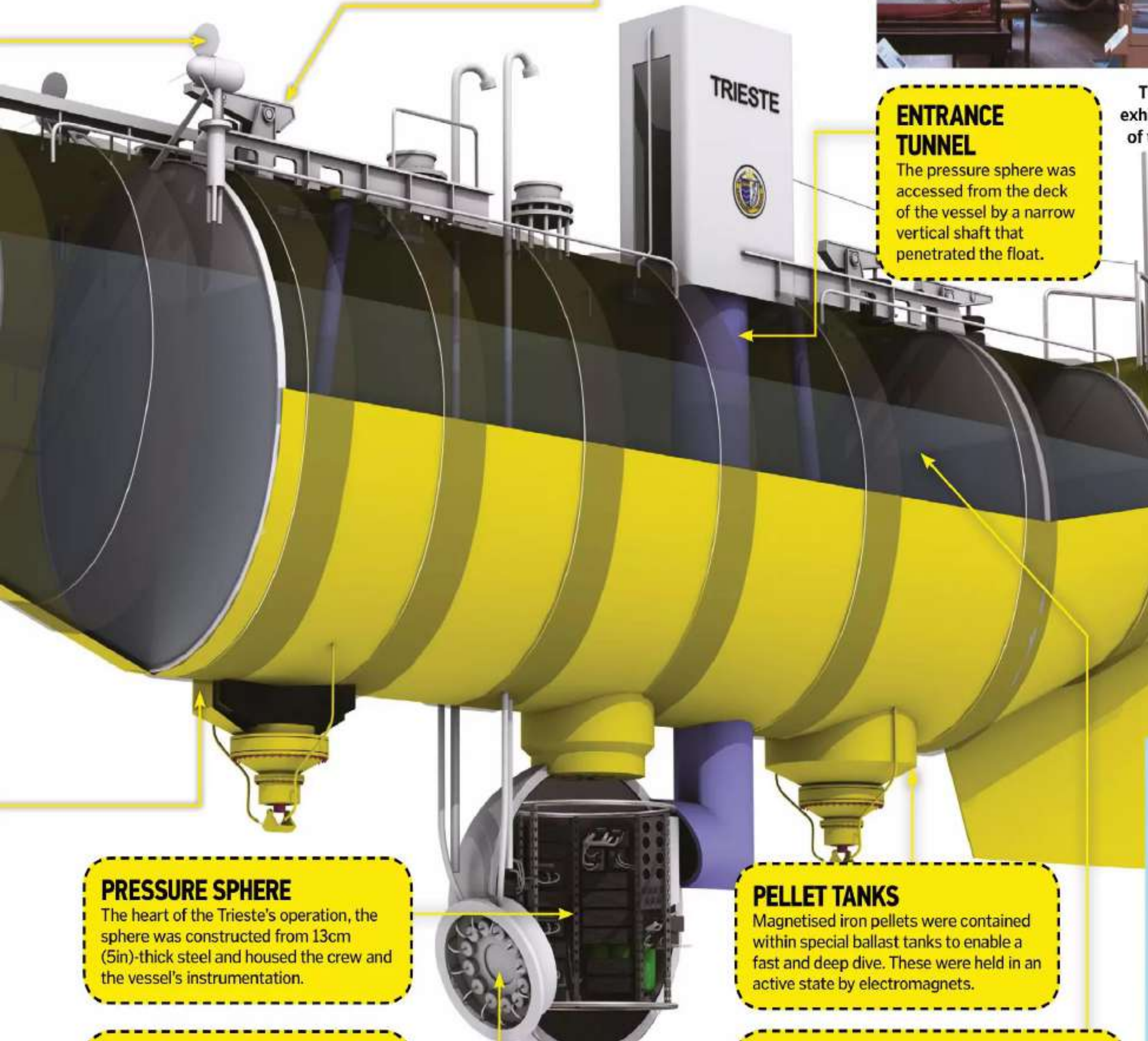
INSIDE THE BATHYSCAPHE TRIESTE

HOW IT WORKS TAKES A LOOK AT THE MACHINERY AND TECHNOLOGY THAT ENABLED THIS RECORD-BREAKING DIVE



One of the specially designed ballast tanks that worked with magnetised iron pellets

The Bathyscaphe Trieste is now exhibited at the National Museum of the US Navy in Washington DC



ELECTROMAGNETS

The magnetic iron pellets that allowed the Trieste to descend so deep were held in place actively by large electromagnets. As such, if there was an electrical failure, the vessel would automatically begin to rise.

ENTRANCE TUNNEL

The pressure sphere was accessed from the deck of the vessel by a narrow vertical shaft that penetrated the float.

HULL

The Trieste's hull was made from steel and held numerous ballast tanks. The pressure sphere that contained the vessel's crew was mounted centrally to its belly.

PRESSURE SPHERE

The heart of the Trieste's operation, the sphere was constructed from 13cm (5in)-thick steel and housed the crew and the vessel's instrumentation.

OBSERVATION WINDOW

The only transparent material on the entire craft, the observation window was made from a cone-shaped block of shatterproof Plexiglas (acrylic glass).

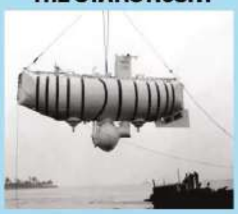
PELLET TANKS

Magnetised iron pellets were contained within special ballast tanks to enable a fast and deep dive. These were held in an active state by electromagnets.

GASOLINE TANKS

Due to the extreme weight of the pressure sphere, large gasoline-filled tanks were used to ensure neutral buoyancy. Gasoline was chosen as it is relatively incompressible at extreme pressures.

THE STATISTICS...



BATHYSCAPHE TRIE STE

Type: Bathyscaphe

Crew: 2

Displacement: 51 tons

Length: 18.1m (59.6ft)

Beam: 3.5m (11.6ft)

Draft: 5.6m (18.6ft)

MAYFLOWER AUTONOMOUS RESEARCH SHIP

HOW WILL THE WORLD'S FIRST FULL-SIZED, FULLY AUTONOMOUS UNMANNED SHIP MAKE IT ACROSS THE ATLANTIC OCEAN?

MARS is 32.5 metres in length and 16.8 metres wide

In 2020, 400 years after the original Mayflower embarked on its historic journey from Plymouth, Britain, to Plymouth, US, another groundbreaking vessel will follow in its wake.

The Mayflower Autonomous Research Ship (MARS) is a multimillion pound project being developed by the UK's Plymouth University, autonomous craft specialists MSubs, and yacht designers Shuttleworth Design. Unlike its namesake, it will be captained remotely so there will be no crew on board, and in addition to wind power it will also be propelled by energy from the Sun.

As well as marking an important maritime anniversary, MARS will serve as a state-of-the-art research platform capable of conducting numerous experiments at sea. Its cargo will include a variety of drones and scientific instruments that will gather meteorological, oceanographic and climate data that can be transmitted ashore for analysis, and the ship itself will serve as a test bed for new navigation software and renewable energy technology. It is also hoped that the project will provide live educational resources to students around the world as they follow the ship's record-breaking maiden voyage across the Atlantic Ocean.

The crossing could take as little as seven to ten days with optimal conditions, but as there is no need for it to stop to refuel or replenish a

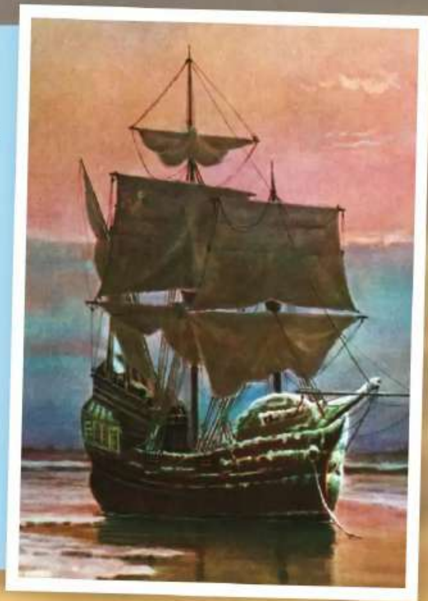
ABOARD THE MARS

THE GROUNDBREAKING DESIGN OF THE CREWLESS LABORATORY AT SEA

THE ORIGINAL MAYFLOWER

In September 1620, 102 passengers boarded a merchant ship called the Mayflower in Plymouth, Britain, ready to start a new life across the Atlantic. The ship was usually used to transport wine and dry goods, but for this trip, a group of Protestant Separatists made up the cargo. Disgruntled with the Church of England, which they believed to be corrupt, they hoped to find religious freedom and establish a new church in the New World.

Their journey had originally begun a few months earlier when the Mayflower set sail alongside the Speedwell, but both ships had to return to port when the Speedwell sprung a leak. The delay meant the Mayflower eventually had to make its crossing during storm season, resulting in rampant seasickness and one passenger being swept overboard. However, after two months, the Pilgrims made it to America and set up their own colony, which they named Plymouth.



The Mayflower played an important role in the European colonisation of what later became the United States

"MARS WILL SERVE AS A STATE-OF-THE-ART RESEARCH PLATFORM"

crew, it may be at sea for seven to ten months in order to collect as much data as possible.

Construction of MARS has taken two years, with trials planned for 2019. As there will be no one on board to repair the vehicle if it encounters problems, engineers must make sure it is as robust as possible before its mission. After completing its Atlantic crossing it will then circumnavigate the globe before being made available for scientists to hire for projects.

It is hoped that MARS will contribute to advancements in marine technology

HOVERBOARDS

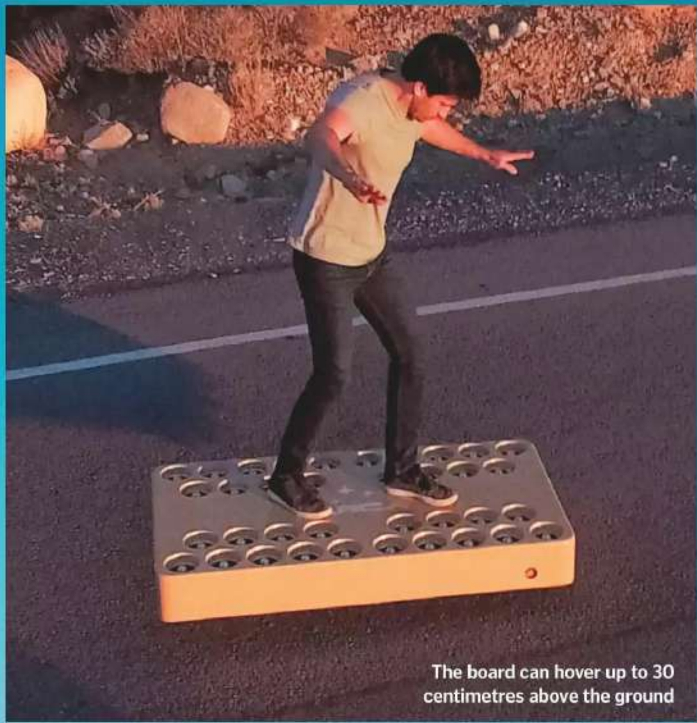
FINALLY! A BOARD THAT FLIES OVER ROCKY TERRAIN AND WATER

When Lexus unveiled its new invention, the futuristic Slide hoverboard, in 2015, the world was disappointed to discover that it could only hover over a special magnetic track, and would not be available to buy. A year later, however, the *Back To The Future II* vision finally became a reality when the ARCA Space Corporation unveiled a commercially available device that can hover above any terrain.

The ArcaBoard uses 36 high-power electric ducted fans to create enough thrust to lift it up to 30 centimetres off the ground. The fans are driven by electric motors, with each one powered by its own lithium-ion polymer battery. This means that if multiple batteries or motors fail, the board will have enough working fans to keep it up. The outer frame is made from aerospace grade composite structures, making it incredibly lightweight, and there's a built-in stabilisation system to aid balance. When switched on, you can control the board with your phone via Bluetooth, but you can also switch it off to steer with your body.

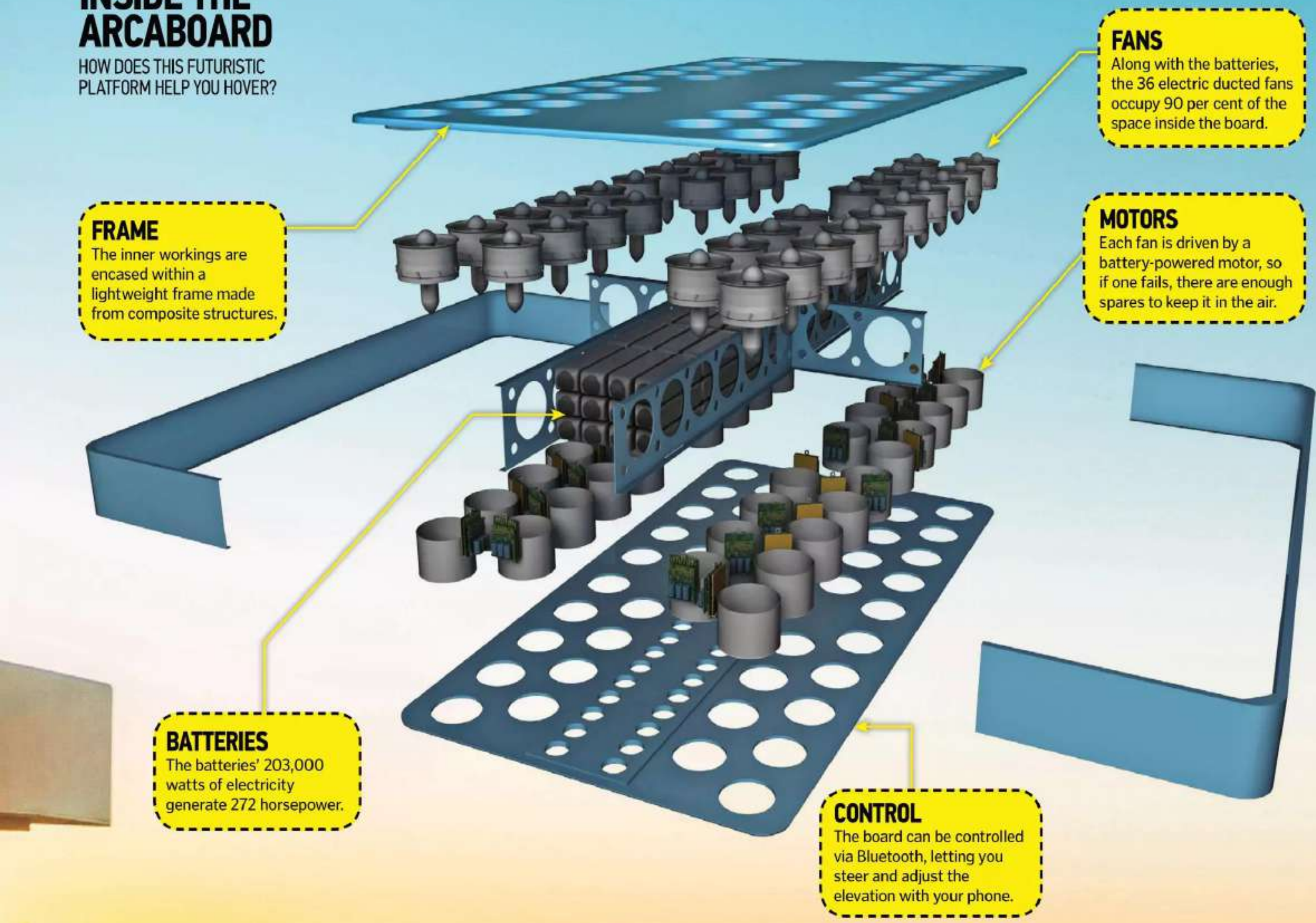
Proximity sensors limit the ArcaBoards's top speed to 20 kilometres per hour, and keep it steady if you accidentally fall off mid-flight. Unfortunately it can currently only hover for six minutes on a single charge, but the special ArcaDock wireless charger will get it back to full power in just 35 minutes.


The ArcaBoard is able to support a 110-kilogram human


The board can hover up to 30 centimetres above the ground

INSIDE THE ARCABOARD

HOW DOES THIS FUTURISTIC PLATFORM HELP YOU HOVER?




Wilbur (right) and Orville attend the Belmont Park Aviation Meet, NY, in 1910

THE AEROPLANE

THE WRIGHT BROTHERS PLAYED A PIVOTAL ROLE IN THE EVOLUTION OF POWERED FLIGHT AND RADICALLY ALTERED THE PATH OF AVIATION HISTORY

Wilbur and Orville Wright are two of history's most famous aviation pioneers who, through a series of experiments in the late 19th and early 20th centuries, created the first controllable, powered, heavier-than-air aircraft. Named the Wright Flyer, the plane was the culmination of over a decade's worth of research and trials that saw the brothers progress from custom-built kites, through to gliders and finally on to engine-powered aeroplanes. Together these talented siblings are generally credited with launching the age of powered flight.

The Wright brothers were the sons of Milton Wright, an ordained minister of the Church of the United Brethren in Christ, and Susan Catherine Koerner Wright. The family lived in various locations including Richmond, Indiana; Cedar Rapids, Iowa; and Dayton, Ohio – the latter for the majority of their' lives.

Orville would later go on to explain that his father had encouraged both of them from an early age "to pursue intellectual interests and to investigate whatever aroused curiosity". This led Orville and Wilbur into a diverse range of interests and expertise including printing, bicycles – which the pair sold and repaired for several years – and the construction of various machines from wood and metal. Both engineers and inventors, the brothers eventually became well known for their academic and practical application of modern engineering, with Wilbur especially spending much time in his father's and public libraries.

One of their heroes was German gliding pioneer Otto Lilienthal, who up until his death in 1896 had built and flown a series of aircraft to varying degrees of success. His death, however – which was the result of a glider crash – oddly spurred the brothers' interest in flight, with them writing to the Smithsonian Institution for suggestions on other aeronautical manuscripts. One of the museum's recommendations was the engineer Octave Chanute, a leading authority on aviation and civil engineering at the time.

With Chanute's help the brothers began conducting a number of aeronautical experiments. Crucial to their approach was the focus on control of the aircraft, advancing previous designs that could only fly in a straight line by introducing a helical twist across the wings in either direction. The brothers tested this configuration in 1899 and, after discovering that it allowed the acute control of a kite, began working on a full-scale model: the first Wright Glider. It was tested in October 1900 at Kitty Hawk, North Carolina, where although lifting off the ground, it produced disappointing results.

The Wright brothers refined their glider and tested it in 1901, then again in October 1902 after spending the summer undertaking a vast series of tests into more efficient wing designs. This third model was the breakthrough, with the glider performing exactly as predicted. The pair – who each piloted the glider in turn – racked up almost 1,000 flights between them over a two-month period, covering distances at Kitty Hawk of up to 190 metres.

Realising they had cracked both the aerodynamic and control issues that all of their predecessors had struggled with, the two brothers turned their attention to a power plant for the glider. In 1903 they built their own four-cylinder internal combustion engine and returned to Kitty Hawk to trial it. Unfortunately the first attempt ended in the engine stalling during takeoff and the front of the plane getting damaged, but after a couple of repairs, the second flight ended in resounding success.

Lifting off at 10.35am on 17 December 1903, the Wright Flyer flew 36 metres, then 53 metres, followed by 60 metres before finally achieving a distance of 259.7 metres. This series of flights heralded a new era of aviation and propelled the Wright brothers and their aeroplane to worldwide fame.

THE BIG IDEA

Prior to the Wright brothers' successful flight (pictured below), many other scientists and engineers had dreamed about and, to varying degrees of failure, attempted to build machines that could not only defy gravity, but do so in a controlled manner. Their failures left the idea of a non-dirigible method of flight as mere fancy, with materials, aerodynamics and energy supplies all seeming insurmountable obstacles.

What is testament to the Wright brothers' expertise is that they addressed each one of these issues with their aircraft in turn, solving in years what countless minds had failed to address in centuries. Examples include the testing of hundreds of wing designs in a custom-built wind tunnel to determine which shape best granted lift, designing and building their own four-cylinder internal combustion engine that was adapted for air travel, and recognising that propeller blades could be understood as rotary wings.

A LIFE'S WORK

THE MAIN MILESTONES THAT LED TO THE WRIGHT FLYER TAKING OFF

1867
Wilbur is born, with Orville arriving four years later.

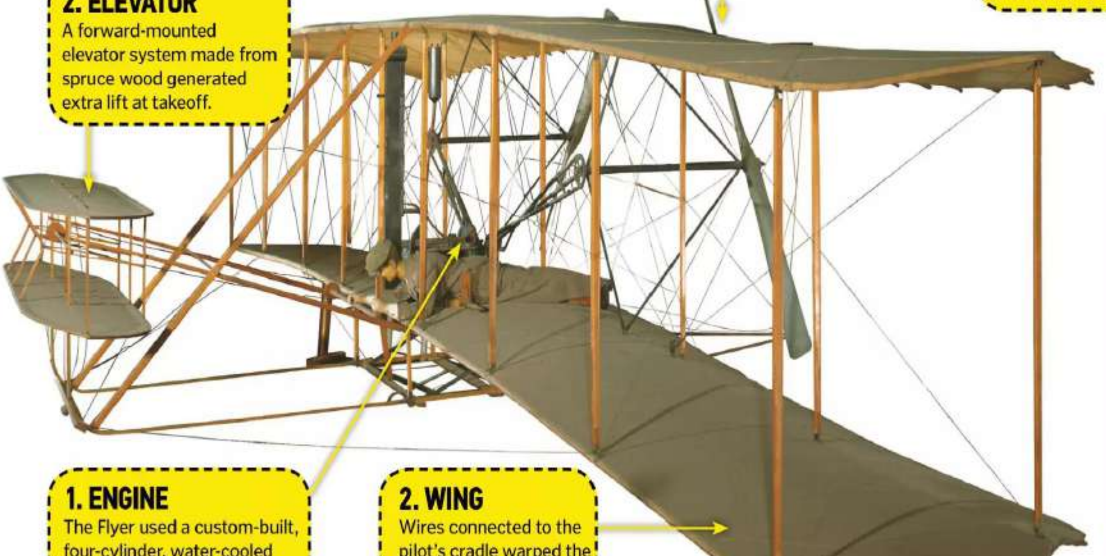
1869
The Wright family moves to Dayton, OH, due to the father's work commitments.

1892
Both brothers team up to open a bicycle repair shop. They begin building bikes a few years later.

1900
Years of research lead to the brothers testing the Wright Glider (right), an unpowered biplane with a forward elevator for pitch control.

THE WRIGHT FLYER IN FOCUS

TAKE A CLOSER LOOK AT THE PINNACLE OF THE WRIGHT BROTHERS' AVIATION CAREERS



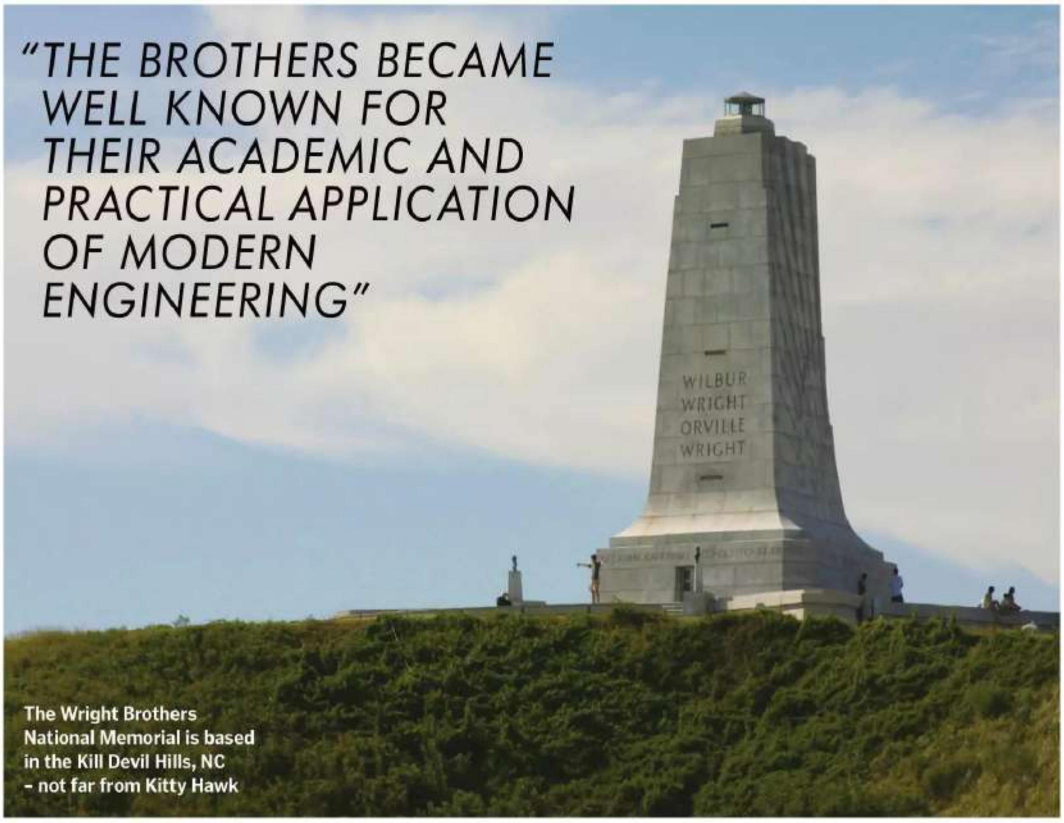
2. ELEVATOR
A forward-mounted elevator system made from spruce wood generated extra lift at takeoff.

2. PROPELLER
Two large propellers were driven by a sprocket chain drive, granting the Flyer a small amount of thrust.

1. ENGINE
The Flyer used a custom-built, four-cylinder, water-cooled piston engine, which could produce about 9kW (12hp).

2. WING
Wires connected to the pilot's cradle warped the wings when the plane's rudder was adjusted.

"THE BROTHERS BECAME WELL KNOWN FOR THEIR ACADEMIC AND PRACTICAL APPLICATION OF MODERN ENGINEERING"



The Wright Brothers National Memorial is based in the Kill Devil Hills, NC – not far from Kitty Hawk

FIVE FACTS: WRIGHT BROS

1 NO COLLEGE
Wilbur and Orville were the only members of the Wright family who didn't attend college. Orville spent the years learning the printing trade, while Wilbur helped out at the local church.

2 LIFELONG BACHELORS
Neither of the Wright brothers married throughout their lives. Wilbur is recorded as once saying that he "did not have time for both a wife and an airplane".

3 CHILD'S PLAY
In their later lives, the Wright brothers attributed their fascination with flying machines to a small toy helicopter that their father had brought home one day from his travels.

4 TWO LUMINARIES
Both of the brothers extensively catalogued their aviation experiments on paper, which then led to Wilbur Wright delivering an official talk at the highly prestigious Western Society of Engineers in Chicago in 1901. The speech he gave was entitled 'Some Aeronautical Experiments'.

5 HOBBY TO BUSINESS
In 1909, the Wright Company was incorporated with Wilbur as president and Orville as one of two vice-presidents. Wilbur died in 1912, and Orville sold the company three years later.

1903
The brothers successfully fly the Wright Flyer in sustained flight at Kitty Hawk, NC. Its fourth flight covers 259.7 metres in just 59 seconds.

1909
The Wright Company sells the first-ever military aircraft, the Wright Military Flyer (right), to the US Army Signal Corps.

1912
Wilbur dies of typhoid fever on 30 May at 45 years old.

1915
Orville ends his leadership of the Wright Company by selling his shares to a group of financiers.

1920
Orville joins the board of the National Advisory Committee for Aeronautics – a precursor to NASA.

1948
Orville suffers a heart attack on 27 January and dies three days later in Dayton, OH, aged 76.

SOLAR-POWERED PLANES

DISCOVER THE TECHNOLOGY AND TEAMWORK BEHIND THE FIRST ZERO-FUEL ROUND-THE-WORLD FLIGHT

"WITHIN THE NEXT FEW DECADES WE COULD BE USING SOLAR-POWERED PLANES COMMERCIALLY"

Each leg of the flight was carefully planned and scheduled to make the most of optimal weather conditions

In July 2010, the experimental aircraft Solar Impulse took to the skies. While it was not the first solar-powered plane, the team behind the Solar Impulse project had achieved a historic feat – they had harnessed the power of the Sun to perform a 26-hour flight, including nine hours overnight. This prototype set eight world records, but it was soon eclipsed by its successor.

The Solar Impulse 2 (Si2) was completed in 2014, and it was built to perform the first zero-fuel circumnavigation. Si2 exceeded all expectations and flew around the world in a 17-leg journey that took 558 hours and seven minutes in total. The team covered over 43,000 kilometres at an average speed of 75 kilometres per hour, all with no fuel.

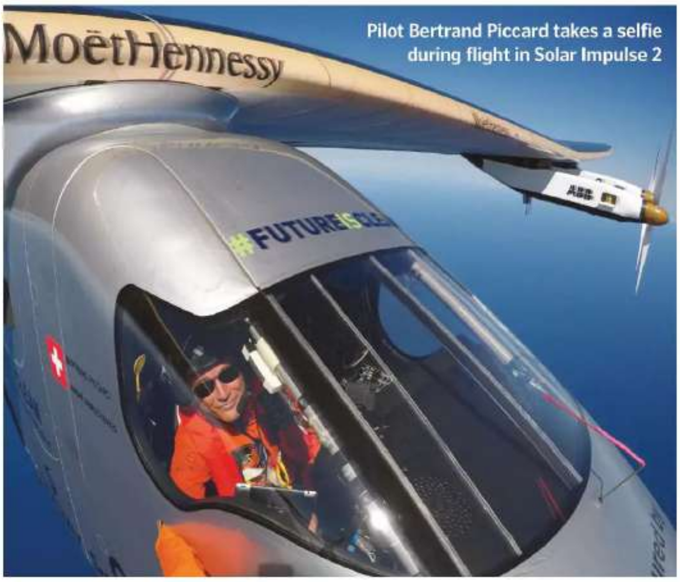
Aviation is responsible for more than two per cent of the world's carbon emissions, so the pressure is on to reduce the amount of fossil fuels being used. Engineers and scientists are currently exploring a range of options, but with concerns surrounding hydrogen fuel safety and with biofuels yet to break into the aviation sector, some manufacturers have set their sights on solar power.

Just like with domestic solar roof panels, Si2 uses devices called photovoltaic cells, or solar cells, to generate electricity from sunlight. These cells are very thin and made with silicon, which is a semiconductor – a material that can conduct electricity while acting like an insulator. When photons of sunlight hit a cell, it forces electrons to move from one side of the silicon wafer to the other. This flow of electrons creates a current, generating electricity that can be harnessed by an attached circuit. Si2 has over 17,000 of these cells installed across its surface. The electricity that is generated powers the plane's motors (which turn the propellers) and also charges the onboard batteries for flying at night.

Solar Impulse sought to push the boundaries not just to set a world record, but to prove that this technology could be a viable option for the future of flight. CEO, co-founder and pilot André Borschberg said in a statement, "Flying around the world is a real challenge. More than a demonstration, it's the confirmation that these technologies are truly dependable and reliable."

Borschberg and his fellow pilot Bertrand Piccard were no strangers to big challenges. Seasoned adventurer Piccard set a record when he completed the first ever non-stop balloon flight around the world in 1999, while ex-Swiss Air Force pilot Borschberg had already faced his own run-ins with danger, surviving a helicopter crash and an avalanche accident. Their circumnavigation project would face technical issues and poor flying conditions, but the combined skills and experience of the pilots and the Solar Impulse team ensured the journey was a success.

Unsurprisingly for a solar plane, the best time for take off is in the morning so as to make efficient use of the daylight hours. As with all flights, weather is an important factor, but it was particularly important for the Si2. While it has the wingspan of a Boeing 747 jet, it only weighs



Pilot Bertrand Piccard takes a selfie during flight in Solar Impulse 2

TO INFINITY AND BEYOND

Despite the breakthroughs made by the Solar Impulse team, there still remains some scepticism about how viable the technology could be for commercial planes.

There is some doubt that the crafts could sustain sufficient power to carry as many passengers as current commercial models. A Boeing 747-400 can transport over 300 passengers at a cruising speed of about 910 kilometres per hour. In contrast, the Solar Impulse is the same width but is only able to carry a single passenger at an average speed of 75 kilometres per hour.

This would also lengthen a flight from London to New York from about 7.5 hours to over three days, assuming that the solar aircraft would be at top speed for the entire transatlantic crossing.

Solar Impulse engineers are keen to find solutions to overcome the logistical challenges of solar flight

as much as a family car, so strong winds during take off or landing would easily blow it off course. In order for a flight to commence, a combination of battery power and solar energy first have to start to turn the propellers. Then, with its nose titled up, the lightweight craft smoothly ascends into the air.

It rises slowly, past the turbulent jet stream at 35,000 feet (10,668 metres) up into the clouds. The pilot must skilfully dodge any dense clouds that will otherwise block the all-important sunlight from reaching the solar panels. To turn the plane, a propeller on one side of the wings speeds up. The solar panels charge the plane's batteries during the day, with the plane climbing to 28,000 feet (8,534 metres) and gliding to 5,000 feet (1,524 metres) to conserve energy at night. When it is time to land, the power to the propellers is shut off and the craft glides back down to terra firma.

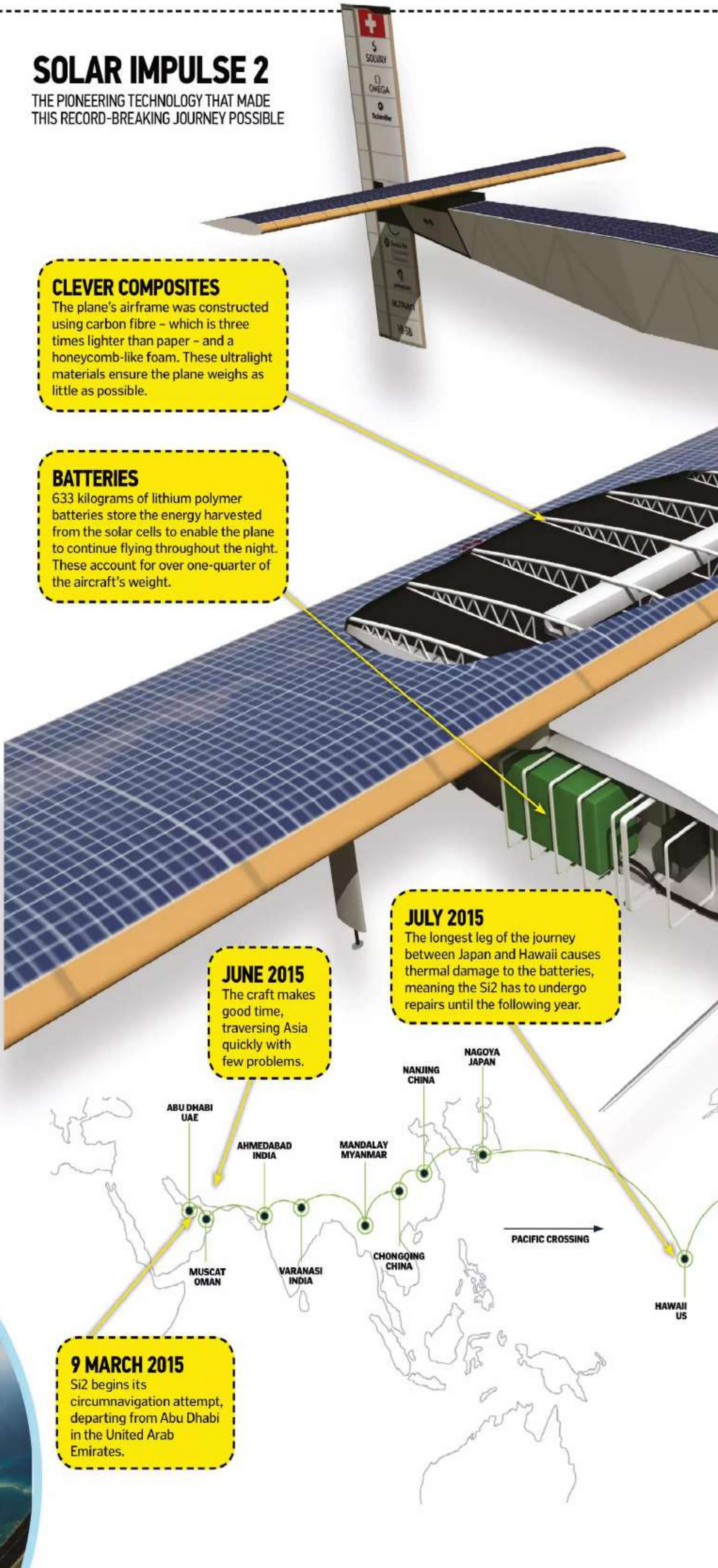
The two pilots alternated between each leg of the flight. Despite the one-seater plane only being able to carry a single pilot at a time, they were never alone in the sky – on the ground, the support team were dedicated to keeping them safe. They started in Abu Dhabi before travelling eastward across Asia, crossing the Pacific, the US, the Atlantic and Europe before finally returning to Abu Dhabi. The longest journey was the Pacific crossing, completed in 117 hours and 52 minutes by André Borschberg.

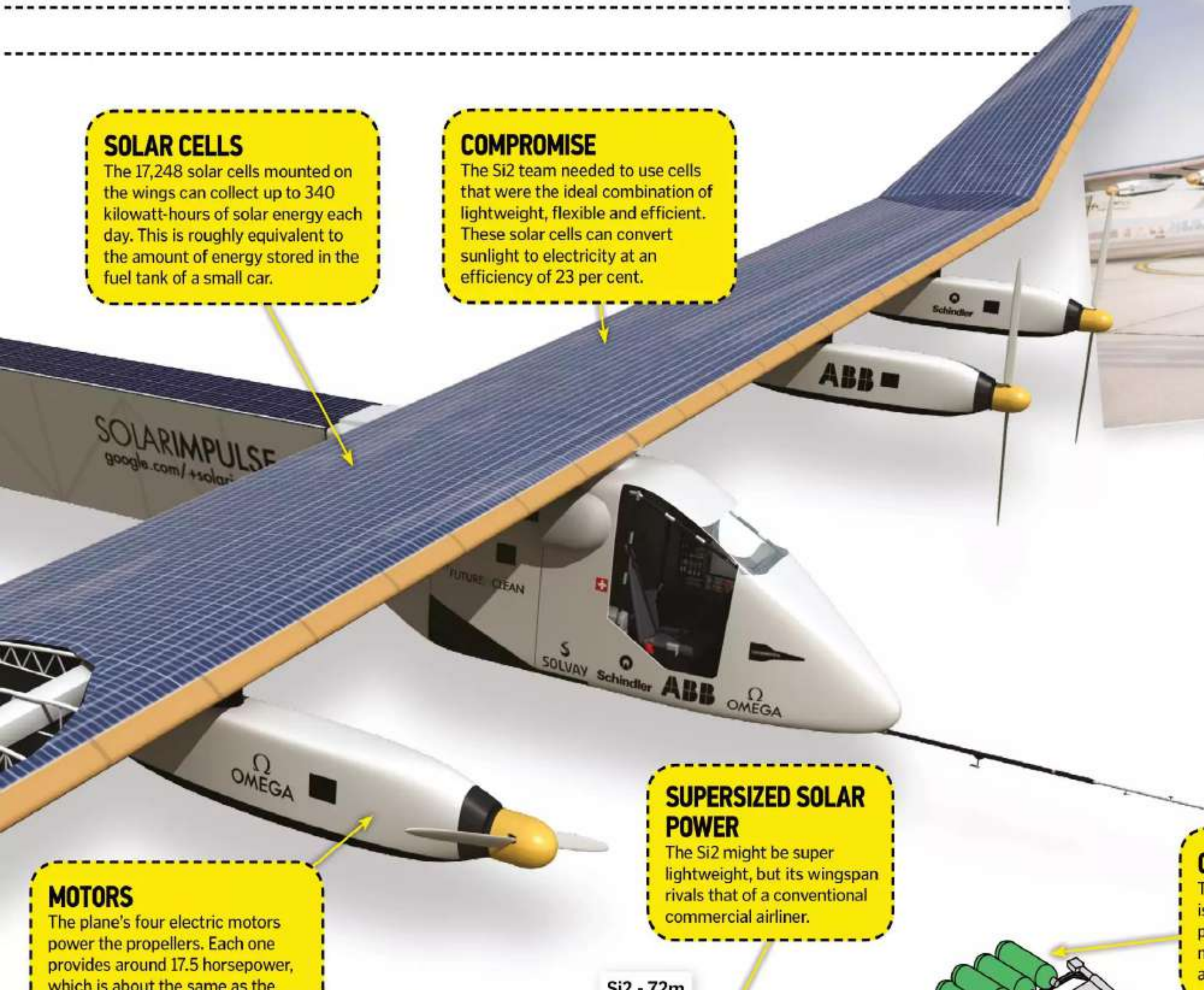
So is this the future of green technology? We still have a long way to go, but it's not unrealistic to imagine that within the next few decades we could be using solar-powered planes commercially. Solar Impulse exceeded all expectations, proving just how much we can achieve already.

After landing at the final stop on this incredible journey, Bertrand Piccard addressed the crowd awaiting him: "This is not only a first in the history of aviation; it's before all a first in the history of energy. I'm sure that within ten years we'll see electric airplanes transporting 50 passengers on short- to medium-haul flights. Solar Impulse is only the beginning. Now take it further!"

SOLAR IMPULSE 2

THE PIONEERING TECHNOLOGY THAT MADE THIS RECORD-BREAKING JOURNEY POSSIBLE





SOLAR CELLS

The 17,248 solar cells mounted on the wings can collect up to 340 kilowatt-hours of solar energy each day. This is roughly equivalent to the amount of energy stored in the fuel tank of a small car.

COMPROMISE

The Si2 team needed to use cells that were the ideal combination of lightweight, flexible and efficient. These solar cells can convert sunlight to electricity at an efficiency of 23 per cent.

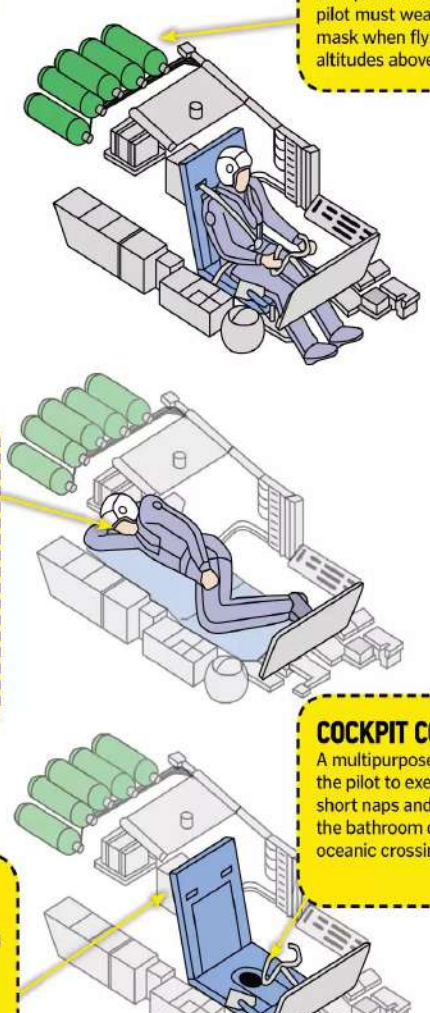
More than just the pilots, Bertrand Piccard (left) and André Borschberg (right) are the chairman and CEO respectively of Solar Impulse, and advocates of clean energy solutions

MOTORS

The plane's four electric motors power the propellers. Each one provides around 17.5 horsepower, which is about the same as the engine of a small motorbike.

SUPERSIZED SOLAR POWER

The Si2 might be super lightweight, but its wingspan rivals that of a conventional commercial airliner.



OXYGEN TANKS

To save weight the cockpit isn't pressurised, so the pilot must wear an oxygen mask when flying at altitudes above 3,600m.

AUTOPILOT PRECAUTIONS

An autopilot system takes over while the pilot takes short breaks. If any abnormalities in the instruments' readings are detected the pilot is alerted with a vibration (which is sent via armbands on their flight suit) and an alarm.

COCKPIT COMFORT

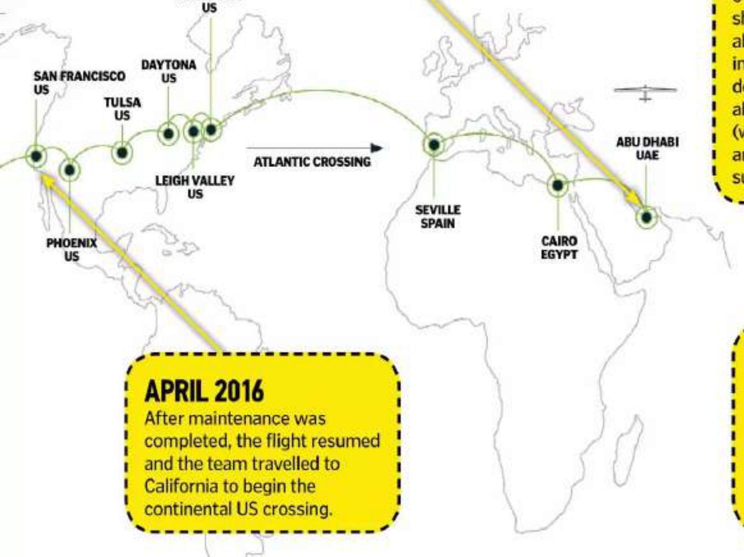
A multipurpose seat allows the pilot to exercise, take short naps and even go to the bathroom during long oceanic crossings.

SAFETY GEAR

In case of emergency, a survival kit, parachute and life raft are stored in the back of the seat. Luckily they weren't needed during the journey.

JULY 2016

On the home straight, Si2 crossed the Atlantic and the Mediterranean before returning to Abu Dhabi, completing its record-breaking journey.

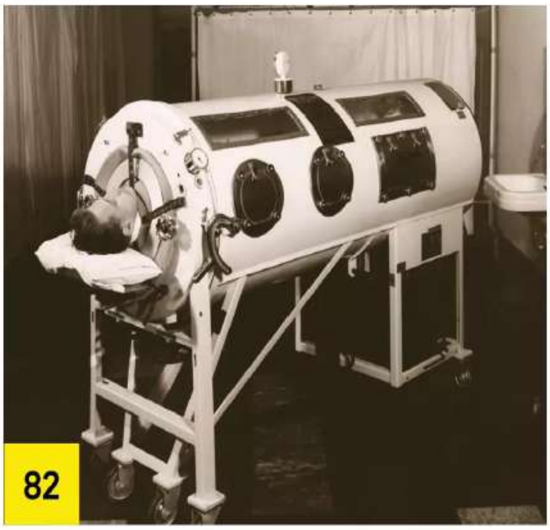


APRIL 2016

After maintenance was completed, the flight resumed and the team travelled to California to begin the continental US crossing.

© Illustration by Adrian Mann; Solar Impulse

MEDICINE



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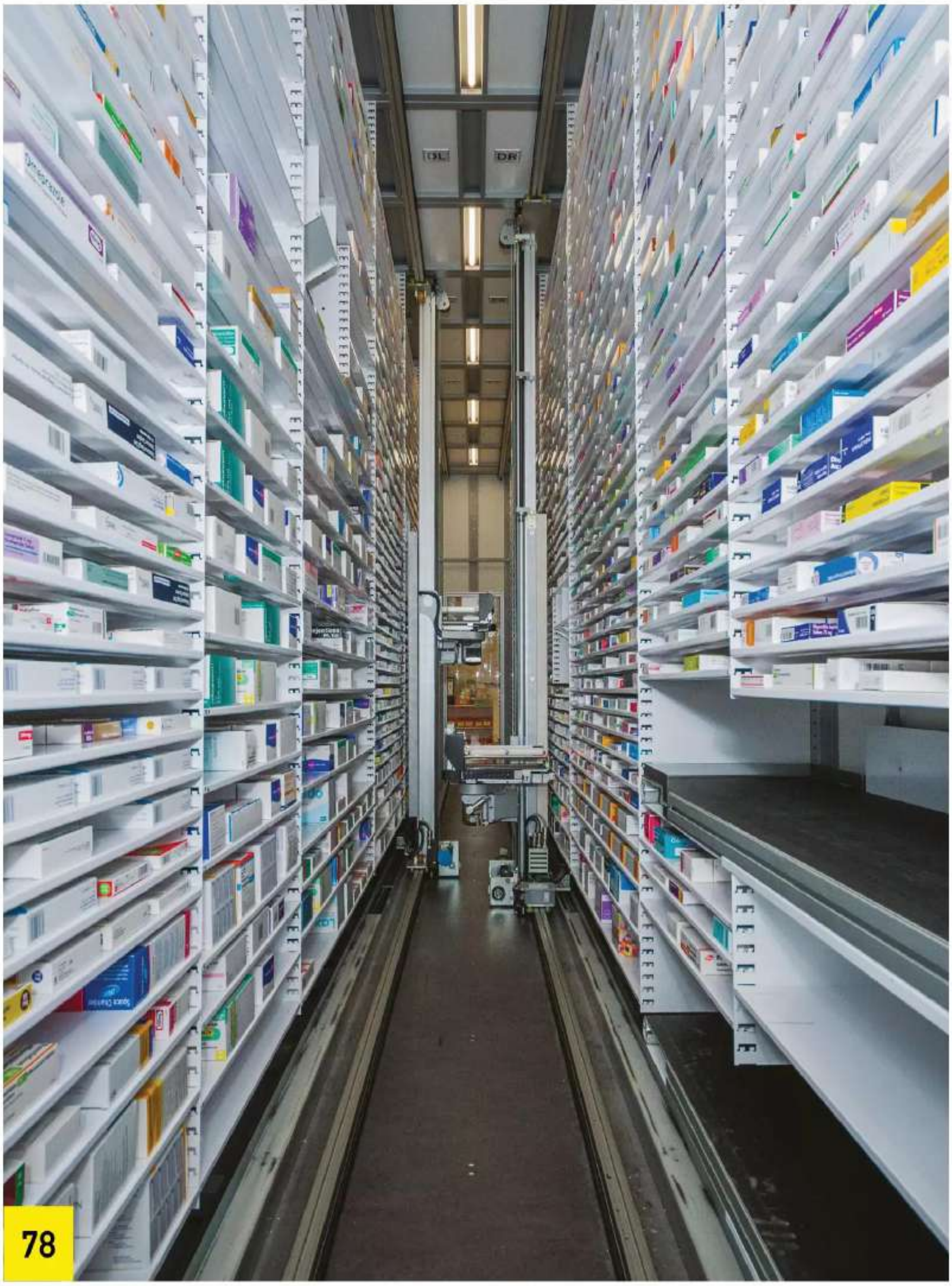

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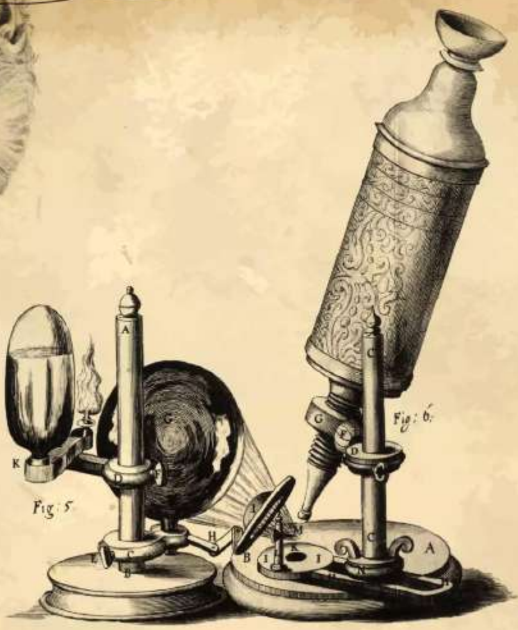


HISTORY'S GREATEST MEDICAL INVENTIONS

WHETHER THEIR TECHNOLOGIES WERE STUMBLED ACROSS BY ACCIDENT OR THE RESULT OF YEARS – PERHAPS MILLENNIA – OF DEVELOPMENT, WE HAVE MANY PEOPLE TO THANK FOR THESE LIFE-SAVING DEVICES

Preventing the spread of disease, improving diagnosis and saving lives are just three of the many ways in which medical inventions have changed our world. With so much cutting-edge technology dominating the headlines, from stem cells to genome editing, it's often easy to forget the impact that simple inventions like the wheelchair and the thermometer have had on our lives. We can't always put our finger on the person responsible for each of them either – often they are the result of many minds working together, standing on the shoulders of their forefathers. Where patent records and other important documents have been lost to the abyss of time, so too has our memory of those great inventors of yore. But with a little bit of digging, we can attempt to piece their histories together.

The first British gas mask used in warfare, known as the Black Veil Respirator, consisted of a mouth pad soaked in an absorbent solution

GAS MASK
JOHN SCOTT HALDANE, SCOTLAND, 1915

WITH THE EMERGENCE OF CHEMICAL WARFARE ON THE BATTLEFIELDS OF WORLD WAR I, A PROTECTIVE MASK HAD TO BE INVENTED – AND FAST

When the German army unleashed their secret weapon upon Allied soldiers in April 1915, none were prepared. A thick, yellow cloud of poison gas advanced across No Man's Land and within ten minutes, thousands had died from asphyxia or been permanently blinded.

In the weeks that followed, soldiers were issued with cotton mouth pads soaked in urine, as it had been discovered that ammonia helped to neutralise chlorine. These were quickly replaced by the Black Veil Respirator, invented by John Scott Haldane, which was treated with a far less stomach-churning, sodium-based solution.

It wasn't until July that troops would receive their first full-face gas masks. The British Smoke Hood fitted over the entire head and was made of a chemical-absorbing fabric, while a thermoplastic window provided visibility. It had been invented by by Dr Cluny Macpherson, a Newfoundland physician who who had been enlisted into the Allied forces. However, it wasn't in use for long as by summer of the following year, the Small Box Respirator had been introduced, which consisted of a face mask with glass eye-pieces, connected via a rubber hose to a metal 'small box' filter containing chemical absorbents. This remained the most effective and practical gas mask until well beyond the end of the war.

Early gas masks were essentially hoods that had been treated with chemicals to protect against chlorine

French physician René Laennec invented the stethoscope in order to make his appointments with female patients more dignified

STETHOSCOPE
RENÉ LAENNEC, FRANCE, 1816

IT WAS ONLY OUT OF EMBARRASSMENT THAT THIS NOW-INVALUABLE MEDICAL DEVICE WAS INVENTED

Imagine going to the doctor and being asked if he or she could listen to your heart, only for them to proceed to place their ear against your chest. Awkward, right? In the days before stethoscopes, this was how it was done. Physician René Laennec found it incredibly undignified, especially when a lady was involved, so resigned himself to inventing a solution. Upon watching children sending signals using long, hollow sticks, he came up with a device that would enable him to listen to a patient's heartbeat at a polite distance. His first design consisted simply of a tightly rolled piece of paper, which when placed between the chest and his ear, could amplify the sound of the heart. He then translated his design into a hollow wooden cylinder, adding a funnel at one end that augmented the sound. He named his instrument the 'stethoscope', from the Greek words stethos, meaning chest, and skopos, meaning examination.

The stethoscope quickly gained popularity and spread across Europe. The first flexible versions were invented a decade or two later, while in 1851, Irish physician Arthur Leared invented the binaural stethoscope, which fitted into both ears. Eventually, in 1852, the design was standardised by American George Philip Cammann.

Laennec's stethoscope was little more than a hollow wooden cylinder

THERMOMETER
DANIEL GABRIEL FAHRENHEIT, NETHERLANDS, 1714

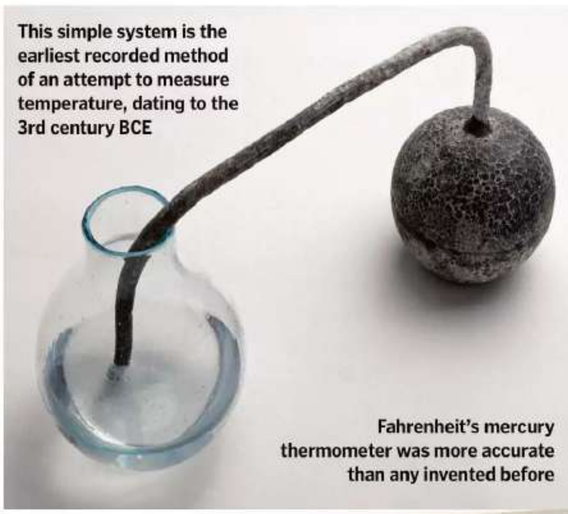
IT WASN'T UNTIL THE 18TH CENTURY THAT A STANDARDISED THERMOMETER DESIGN WAS CREATED

There are many claimants to the title 'inventor of the thermometer', and that's because its development came in several stages over the course over almost 2,000 years. Philo of Byzantium, who lived during the 3rd century BCE, performed the first recorded experiment involving the expansion and contraction of air in different temperatures. He connected a tube between a hollow sphere and a jug of water, and as the air in the sphere cooled and therefore contracted, water rose up the tube from the jug.

In the 16th century, Galileo Galilei, or one of his colleagues, invented the thermoscope. This was very similar to Philo's contraption, but the tube rose up vertically out of the water and the hollow sphere was at the top. Scales were added, but these were not standardised and the devices suffered in that they were also sensitive to air pressure.

Ferdinand II, grand duke of Tuscany, improved the design with the invention of the first sealed glass thermometer, which was a sealed cylinder filled to a certain height with coloured alcohol. Small glass bubbles filled with air at different pressures hovered in the liquid, changing positions as the temperature rose or fell.

But it was Daniel Gabriel Fahrenheit – the inventor of the eponymous temperature scale – who created the first reliable 'modern' thermometer in 1714, which used mercury instead of water or alcohol to provide a finer scale, and went on to become the standard design for centuries to come.



This simple system is the earliest recorded method of an attempt to measure temperature, dating to the 3rd century BCE

Fahrenheit's mercury thermometer was more accurate than any invented before

OPHTHALMOSCOPE
HERMANN VON HELMHOLTZ, GERMANY, 1851

THERE IS SO MUCH MORE TO THIS LITTLE DEVICE THAN MEETS THE EYE...

The ophthalmoscope is one of medicine's most important instruments. It enables opticians and doctors to closely examine the interior surface of the eye, which is useful not only for accurately prescribing glasses, but also for examining retinal blood vessels and detecting high blood pressure and arterial disease. Glaucoma and tumours can also be discovered with it.

Though the 'father of the computer' Charles Babbage invented an ophthalmoscope of sorts, it was German scientist Hermann von Helmholtz who, following his studies of the human eye, independently invented the one that would be recognised as useful. He noticed that he could focus the light reflected from the retina to produce a sharp image of the tissue. Using reflecting glass and a concave lens, he developed a way to enable physicians to illuminate the retina and observe it at the same time.

Andreas Anagnostakis, an ophthalmologist from Greece, came up with the idea of making the instrument handheld by adding a concave mirror. Austin Barnett created a model for Anagnostakis, which he used in his practice and presented at the first Ophthalmological Conference in Brussels in 1857, following which the instrument became very popular. In 1915, Francis A Welch and William Noah Allyn invented the world's first handheld direct illuminating ophthalmoscope. Today, ophthalmoscopes equipped with electric illumination are still used in research and diagnostics.

Ophthalmoscopes, which are used to examine the interior surface of the eye, now feature electric illumination

HYPODERMIC SYRINGE
CHARLES PRAVAZ OR ALEXANDER WOOD (DISPUTED), FRANCE/SCOTLAND, 1850S

THANKS TO THE HYPODERMIC SYRINGE, MEDICINES CAN BE ADMINISTERED QUICKLY AND SAFELY, BUT AS WITH MOST INVENTIONS, IT'S NOT ENTIRELY CLEAR WHO WE HAVE TO THANK FOR THESE LIFE-SAVING DEVICES

Hypodermic (meaning 'beneath the skin') syringes are used to inject substances into or extract liquids from the body. They consist of a very thin, hollow needle attached to a syringe. Modern needles are designed to reduce contamination in two ways: firstly, their incredibly smooth surfaces prevent germs from sticking to them; and secondly, they are incredibly sharp, which means that only the tiniest hole is left, thereby reducing the chance of infection. However, they haven't always been this high-tech. Christopher Wren was the first to experiment with hypodermic needles in the 17th century, using animal bladders as the syringe and goose quills as the needle. It was impossible to perform injections without an incision until after the invention of the hollow needle by Irish physician Francis Rynd in 1844. Frenchman Charles Pravaz took his design and adapted it to create a hypodermic syringe operated by a screw, which controlled the amount of substance injected. It was made entirely of silver. Around the same time in Scotland, Alexander Wood was developing his own hypodermic needles, and can be credited with the popularisation of injections as a medical technique. By 1944, the Chance Brothers' Birmingham glassworks factory was mass producing the first all-glass syringe and a decade later, following concerns about sterilisation, a New Zealand inventor called Colin Murdoch applied for a patent for a disposable plastic syringe.

Francis Rynd invented the first hollow needle in 1844

The Charles Pravaz hypodermic syringe is often credited as being the first of its kind

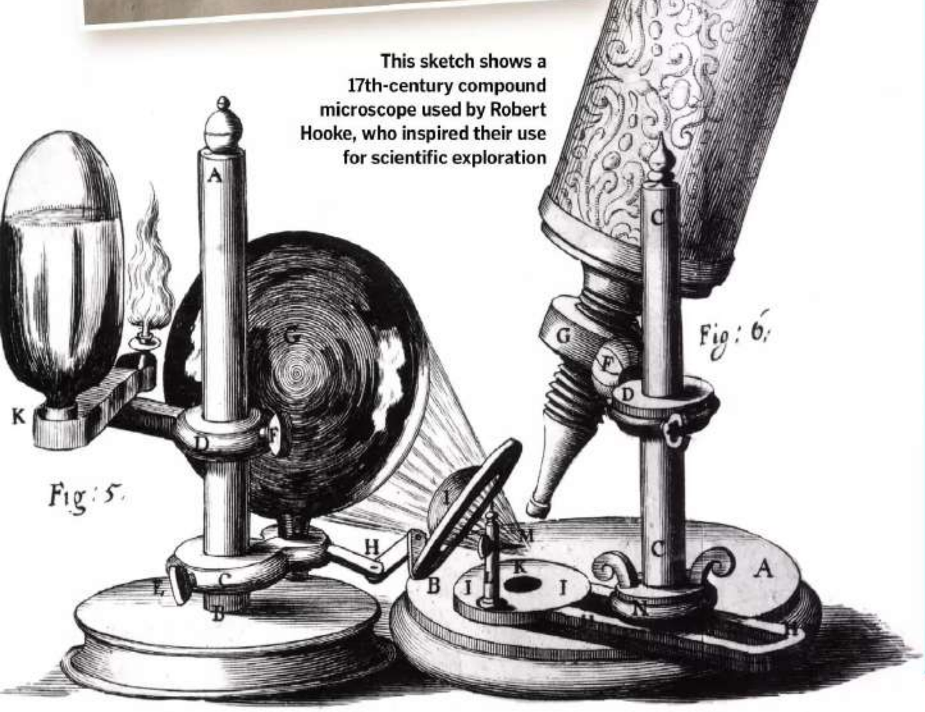
MICROSCOPE
HANS AND ZACHARIAS JANSSEN (DISPUTED), NETHERLANDS, 1590S

WITH THE INVENTION OF THE MICROSCOPE, OUR EYES WERE SUDDENLY OPENED

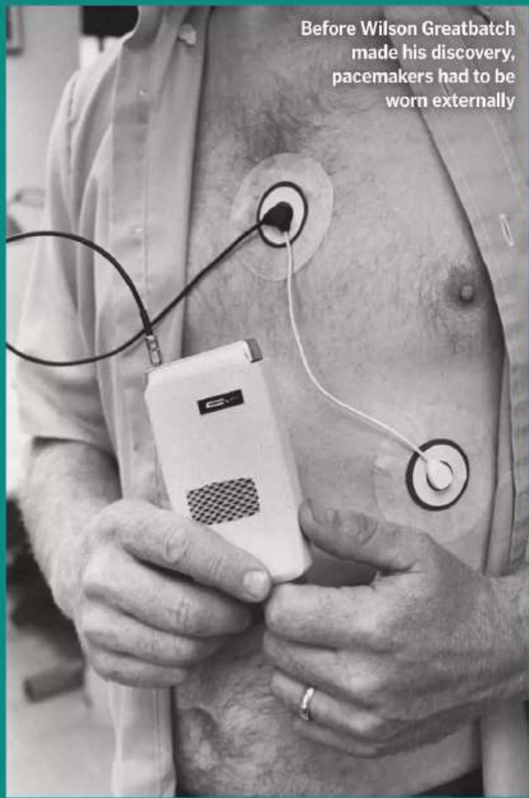
For millennia, humans were only able to see objects that were at least the width of a human hair. Ancient civilisations had experimented with the optical properties of water and, following its invention circa 3000 BCE, glass, but it was with the creation of the eyeglasses in the 13th century that simple microscopes were first used. These were essentially magnifying glasses, consisting of a single lens, and were mainly employed in the examination of tiny insects. They came to be known as 'flea glasses'.

But when we talk about microscopes, what we really mean is 'compound microscopes' – consisting of more than one lens connected by a hollow tube. There is an objective lens at the end nearest the specimen, which produces a primary magnified image, and at the other end is the eyepiece, which magnifies the first image. Several claims to the invention of the compound microscope revolve around the spectacle-making centres in the Netherlands, particularly to father-son duo Hans and Zacharias Janssen, as well as their rival, Hans Lippershey, who applied for the first telescope patent in 1608. Most historians credit the former, thanks to a letter by the Dutch diplomat William Boreel, who in 1650 wrote to the physician of the French king informing him of the invention by the Janssens back in the early 1590s. A Janssen microscope still exists, which dates to 1595, and is capable of magnifying to nine times the true size.


A reproduction of a Janssen microscope, which essentially consisted of two lenses connected by a hollow tube



This sketch shows a 17th-century compound microscope used by Robert Hooke, who inspired their use for scientific exploration


Before Wilson Greatbatch made his discovery, pacemakers had to be worn externally

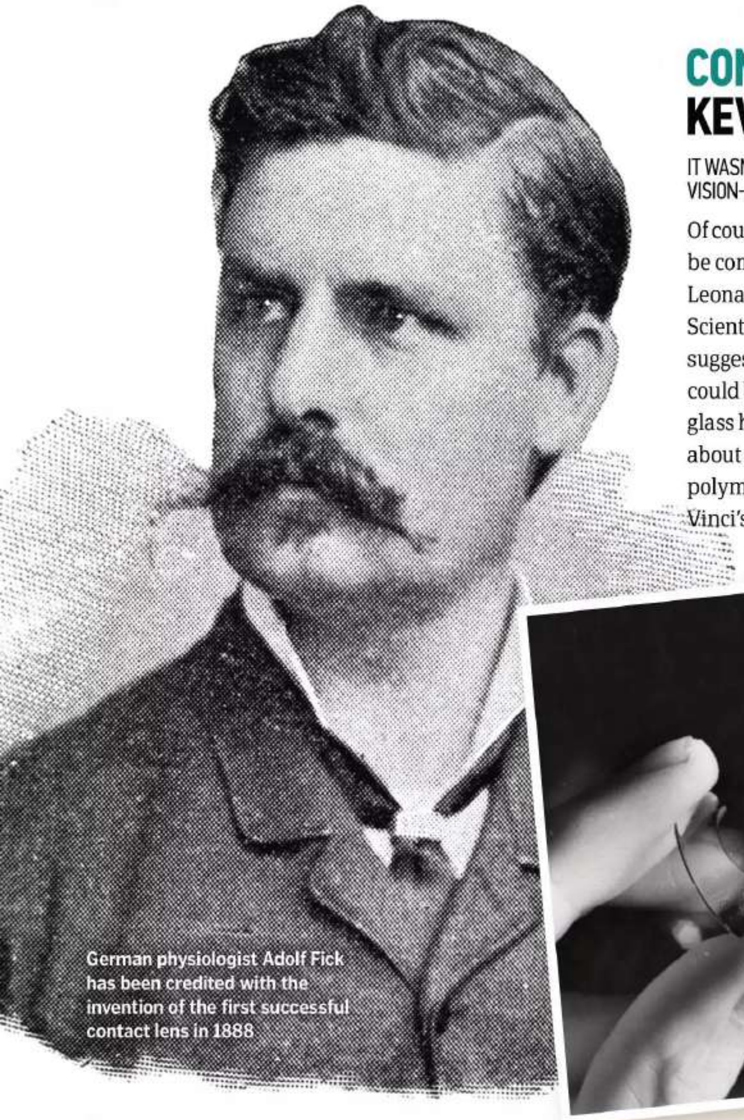
PACEMAKER
WILSON GREATBATCH, USA, 1956

AN ACCIDENTAL INVENTION, THE PACEMAKER ALMOST NEVER MADE IT TO MARKET THANKS TO FEARS OVER DOCTORS INTERFERING WITH NATURE

The pacemaker has its origins in the 19th century, when Scottish physiologist John Alexander MacWilliam discovered that the application of an electrical impulse to a human heart could force the muscles to contract and pump blood. In the 1920s, a device using that technology was used to revive a stillborn child and in 1932, American Albert Hyman created a version with a hand-cranked motor. However, his research was never published, as the public believed he was interfering with nature by 'reviving the dead'.

In the 1950s, external pacing devices were created, but these were bulky and often required mains power. The pacemaker as we know it wasn't invented until 1956. Wilson Greatbatch, an American engineer, was building an oscillator to record heart sounds when he accidentally installed a resistor with the wrong resistance. It began emitting a regular electrical pulse not dissimilar to that produced by a beating heart. He realised that his invention could be used to help a diseased heart stay in rhythm, so over the next two years he perfected his design into a pocket-sized assembly of batteries and resistors. In 1960, it was implanted into a 77-year-old man who went on to live a further 18 months. A patent was granted and Wilson Greatbatch Ltd was created (now Integer Holdings), which still produces pacemaker technology today.

A scientist putting together the components for a pacemaker



German physiologist Adolf Fick has been credited with the invention of the first successful contact lens in 1888

CONTACT LENS
KEVIN TUOHY, USA, 1948

IT WASN'T UNTIL THE 20TH CENTURY THAT A DESIGN FOR A PRACTICAL VISION-CORRECTING CONTACT LENS WAS CREATED

Of course, a history of inventions wouldn't be complete without a mention of Leonardo da Vinci – the original Mad Scientist. It was he who in 1508 first suggested that the power of the cornea could be altered by wearing a water-filled glass hemisphere over the eye. But that's about as far as he got. In 1801, another polymath – Thomas Young – brought da Vinci's sketch to life when he used wax to affix water-filled lenses to his eyes. A few decades later, Sir John Herschel proposed an idea for making a mold of the cornea in order to produce conforming glass lenses, but it wasn't until the 1880s that someone actually did this... and there is some debate as to who did it first. German ophthalmologist Adolf Fick was one of the claimants, as was his compatriot, August Muller. Louis Gerard is another name associated with the invention of the first contact lens. Regardless, all three of their designs covered the entire eye, and could therefore only be tolerated for a few hours. It was a Californian optician, Kevin Tuohy, who introduced the first corneal lenses in 1948, which were plastic, gas permeable, and most resemblant of the contact lenses we know today.

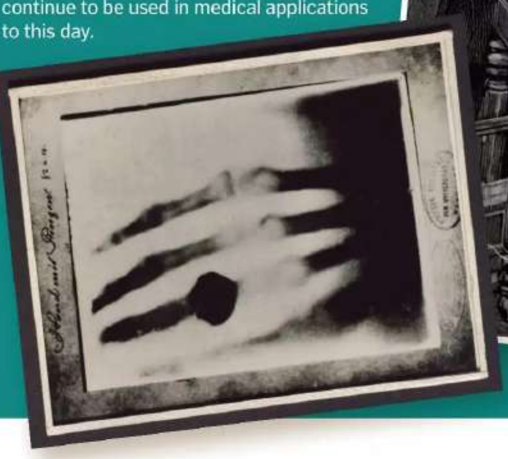
Early contact lenses were made of glass and covered the entire eye, restricting the amount of oxygen to the cornea

X-RAYS
WILHELM CONRAD ROENTGEN, GERMANY, 1895

THIS ACCIDENTAL DISCOVERY TRANSFORMED THE LIVES OF DOCTORS – AND SHOEMAKERS – AROUND THE WORLD

Professor Roentgen was famous for his experiments with cathode ray tubes - glass vacuum tubes containing an electron gun. When the electrons hit a fluorescent screen at the other end of the tube, it lights up, and by controlling where the electrons hit, an image can be made. During one of his experiments, he noticed a fluorescent glow was being created on a material located a few feet away from the tube, despite the fact that he had covered the tube with cardboard to stop the light escaping. He realised that a new kind of ray was being created that was capable of passing through the heavy paper. For the next few weeks, he barely left his laboratory as he investigated the many properties of the rays he called 'X-rays'. He discovered that the rays could pass through human tissue, but not through bones and metal objects, and in late 1895 he took his first photograph of a human body part using X-rays - of his wife's hand. Within a month of announcing his discovery, several medical radiographs had been made and were being used by surgeons to aid them in their work. By the 1920s, X-ray machines were being used in shoe shops to help with fittings. However by the 1950s, concerns about the dangers of X-rays led to the end of this practice, although they continue to be used in medical applications to this day.

Wilhelm Roentgen discovered X-rays by accident when experimenting with cathode rays

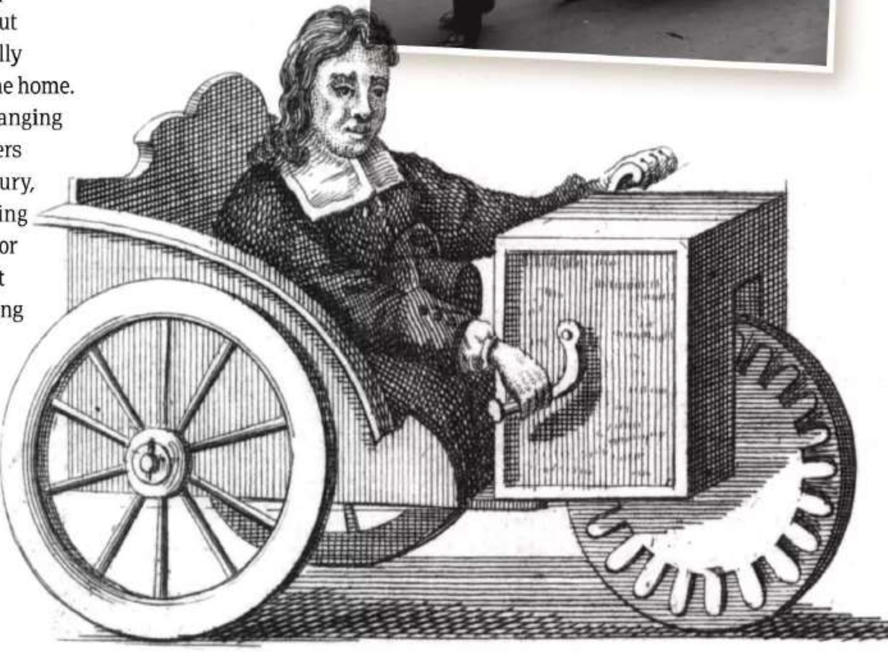


WHEELCHAIR
STEPHAN FARFFLER, GERMANY, 1650

THOUGH THEY DATE BACK TO ANCIENT TIMES, IT WAS A DISABLEDWATCHMAKER WHO REVOLUTIONISED THE WHEELCHAIR'S DESIGN

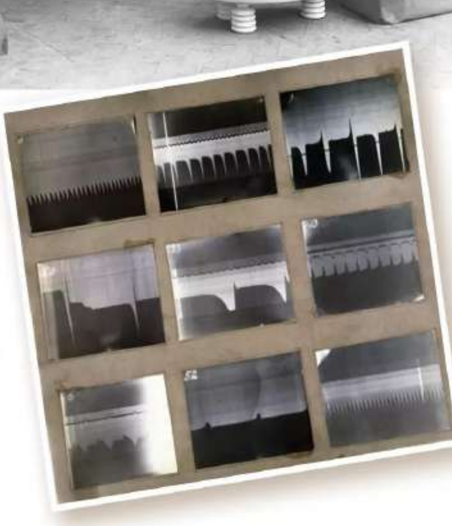
No one knows when wheeled chairs were first used by disabled people. It's likely that it happened around the same time that wheeled furniture was introduced, in the 6th century BCE, but the first surviving records of its occurrence don't appear until 3rd-century-BCE China. Meanwhile, the first recorded use of self-propelled chairs by disabled people in Europe dates to the 17th century. These were invented by a German paraplegic watchmaker called Stephan Farffler and consisted of a three-wheeled, one-person carriage that had hand cranks on the front wheel. However, contrary to their initial purpose, 'invalid chairs' were mainly used as a form of transport by the wealthy. In 1750, James Heath invented the 'bath chair', which featured a folding hood and was pushed or pulled by hand (or, in some cases, by a donkey or horse). These were followed by wooden-framed seats that eventually featured wire-spoke wheels and rubber tyres, but independent use was usually limited to the confines of the home. Perhaps the most game-changing moment for wheelchair users came in the early 20th century, with the invention of a folding version that enabled outdoor use. The developments that followed focused on reducing weight and improving functionality until eventually, following World War II, the first electric wheelchairs were introduced.

Designed for use by the disabled, bath chairs were popular among the wealthy as a relaxed form of transport



The first self-propelled wheelchair was operated via a hand crank attached to the front wheel

The first ECG machines required the patient to submerge their limbs in a conductive saline solution



Electrogram traces taken by August Waller between 1887 and 1903

ELECTROCARDIOGRAPH
WILLEM EINTHOVEN, NETHERLANDS, 1903

WE NOW KNOW THEM AS THE HOSPITAL MACHINES THAT DISPLAY THOSE CHARACTERISTIC PEAKS AND TROUGHS, BUT ECGS HAVEN'T ALWAYS MEASURED HEART ACTIVITY SO ACCURATELY

Animal electricity (galvanism) was discovered by Italian scientist Luigi Galvani in 1786, following an experiment on a dead frog. He observed that when the legs were touched by a copper probe and a piece of iron at the same time, they twitched, just as if an electric current was present. Carlo Matteucci built on his work in the 19th century, becoming the first to detect electrical activity in the heart. However, this tiny current was very hard to record and measure. The problem was solved by British physiologist Augustus Desiré Waller, who used a Lippmann electrometer to produce the world's first ECG machine. This device featured a tube of mercury – a liquid that conducts electricity. When a current from the heart was applied, it caused the mercury to leap up the tube. The change could then be observed through a microscope and photographed. This machine was inaccurate and cumbersome, but a Dutchman named Willem Einthoven witnessed it in action and resigned himself to produce a practical version. He did this using a string galvanometer, which he had invented in 1901, combined with a rotating bicycle. His first prototype weighed 270 kilograms, required five people to operate, and demanded the patient be submerged in vats of conductive saline solution. But the results were astounding. Over the years he improved upon his design, with the development of electrodes eliminating the need for the saline solution. It became invaluable for diagnosing heart conditions and in 1924, he was awarded aNobel Prize.

THE ROBOT PHARMACIST

THE FUTURE OF HEALTHCARE COULD SEE AUTOMATION COME TO THE FOREFRONT

The National Health Service in England treats over 1.4 million patients every 24 hours, so for doctors and nurses time is precious. Any way to make a process more efficient and less time consuming not only makes medical professionals' work easier but could save someone's life.

Automation in healthcare is on the rise and providing the much-needed assistance that medical professionals require. Innovations such as automated robotic pharmacies can lend a helping hand to improve healthcare. Robotic pharmacies as a concept vary in their level of automation, from simply acting as a smart shelf or commonly seen vending machine-style dispensary to a high-tech sorting machine able to recognise and prioritise medicine for optimal efficiency. Their common goal is to act as a librarian of medicine.

At the more advanced end of the robotic spectrum, room-filling machines equipped with smart 'box picking' robotic arms can catalogue, store, dispense and refill their own shelves. Barcodes associated with each medicine are scanned on entry into the machine. Cataloguing can be done manually by a human pharmacist, but some models can identify individual boxes from a heap dropped on a conveyor belt. The interior robotic arms will then collect and store each item, and some have the capacity to hold nearly 42,000 boxes. At the touch of a button, this medicine can be requested and dispensed.

Medicines can be accessed and monitored through smart control panels

Robotic pharmacies have the ability to revolutionise the way doctors and nurses deliver medicine to patients

Medicines dispensed from robotic pharmacists can be sent to different areas of the hospital through delivery tubes

INSIDE AUTOMATION

HOW DO ROBOT PHARMACIES OPTIMISE MEDICINE DISTRIBUTION?

The EvoTec Pharmacy Automated Robot can provide a space saving of 20-25 per cent

UK'S FIRST

Designed by automation experts at Swigglog, the EvoTec Pharmacy Automated Robot was introduced to Poole Hospital, Dorset, England, earlier this year. The first of its kind in the UK, it can hold up to 28,000 items organised by two robotic arms that can load and unload medicines. The arms are able to dispense around 200 items an hour, and the robot monitors expiry dates from the barcodes on the packaging. Air tubes distributed throughout the hospital allow medicine to be delivered at a speedy rate, reducing patient waiting times.

"THEIR COMMON GOAL IS TO ACT AS A LIBRARIAN OF MEDICINE"

AUTONOMY IN THE WARDS

MOXI

The creation of Diligent Robotics, Moxi is the automated robot lending a hand on busy wards. Currently in trials in several Texas hospitals, Moxi uses AI mapping to carry out tasks, including collecting supplies for nurses and setting up patient rooms.

LIGHTSTRIKE

Protection against infection within a hospital ward is a top priority. The LightStrike can deliver high-intensity UV light bursts to surfaces in a patient's room and destroy potential antibiotic-resistant bacteria.

PEPPER

With the ability to recognise faces and detect emotions, Pepper can act as an autonomous helpdesk to undertake reception duties. This robot can also act as a guide, leading patients to different departments.

THE SMALLPOX VACCINATION

ONE OF THE MOST TERRIBLE DISEASES TO HAVE EVER PLAGUED HUMANITY, SMALLPOX CLAIMED THE LIVES OF MILLIONS WORLDWIDE UNTIL IT WAS ERADICATED IN 1980

5 FACTS: EDWARD JENNER

1 Apprentice
Edward Jenner trained from the age of 14 for seven years in Chipping Sodbury, Gloucestershire, under surgeon Daniel Ludlow. In 1770, he became apprenticed at St George's Hospital, Tooting, England.

2 Cuckoo
Jenner was elected Fellow of the Royal Society in 1788 following his publication of an in-depth study of the previously misunderstood life of the nested cuckoo. The report consisted of observations, experiments and dissections.

3 Institution
Off the back of his discovery and creation of the smallpox vaccine, Jenner became heavily involved with the Jennerian Institution in 1803. It was a society that was largely concerned with promoting vaccination and the eradication of smallpox.

4 King
Due to his pioneering medical work, in 1821 Jenner was appointed physician extraordinary to King George IV, which was a great national honour. In the same year he was made mayor of Berkeley, his hometown.

5 Stroke
Jenner died at the age of 73 after suffering from two strokes, the first leaving him paralysed and the second killing him. He was buried in the Jenner family vault at the Church of St Mary, Berkeley.

Nowadays vaccinations are used to prevent hundreds of diseases from hepatitis to yellow fever

While our written records of the disastrous effects of the smallpox disease only extend back to the 15th century, there is compelling evidence that the disease emerged in human populations as far back as 10,000 years ago.

Indeed, upon close examination of the mummified remains of Ancient Egyptian Pharaoh Rameses V (who ruled c.1150-45 BCE), tell-tale pustular rashes can be seen, indicating that he most likely died from the disease. Since its emergence, both strains of the smallpox – variola major and variola minor – were left unchecked, leading up to an estimated 400,000 Europeans dying each year throughout the 18th century. In 1796, however, the game changed.

English physician Edward Jenner realised that individuals who caught the cowpox virus (an incredibly mild and non-deadly variant of the vaccinia virus) did not catch smallpox. Jenner then proceeded to test the theory in a series of cases that even included his own son, infecting each with the cowpox and then smallpox viruses. None of the test cases became infected with smallpox and, as a direct consequence, the first successful vaccine in the world was created.

Here, we explore smallpox, its vaccine and the history of its effects, as well as its eventual eradication.

Full smallpox particles, known as virions

SMALLPOX SYMPTOM

The incubation period for smallpox is roughly 12 days. After this, those infected experience fever, muscle pain, headaches, nausea and backache. These symptoms are then followed by the disease's characteristic pimpled rash across the sufferer's skin, which emerges first on the forehead and then proceeds down the body. Finally, the disease transforms into one of four varieties: ordinary, modified, malignant and haemorrhagic – each of which varies in its overall fatality rate.

JOURNEY TO IMMUNISATION

DEVELOPING INOCULATIONS HAS BEEN A LONG, HARD ROAD, BUT THE DESTINATION WAS WORTH IT

68,000-16,000 BCE
The first smallpox virus evolves from a pre-existing rodent virus in Asia. One clade was the more deadly variola major strains, while the other clade included the less severe types of variola minor.

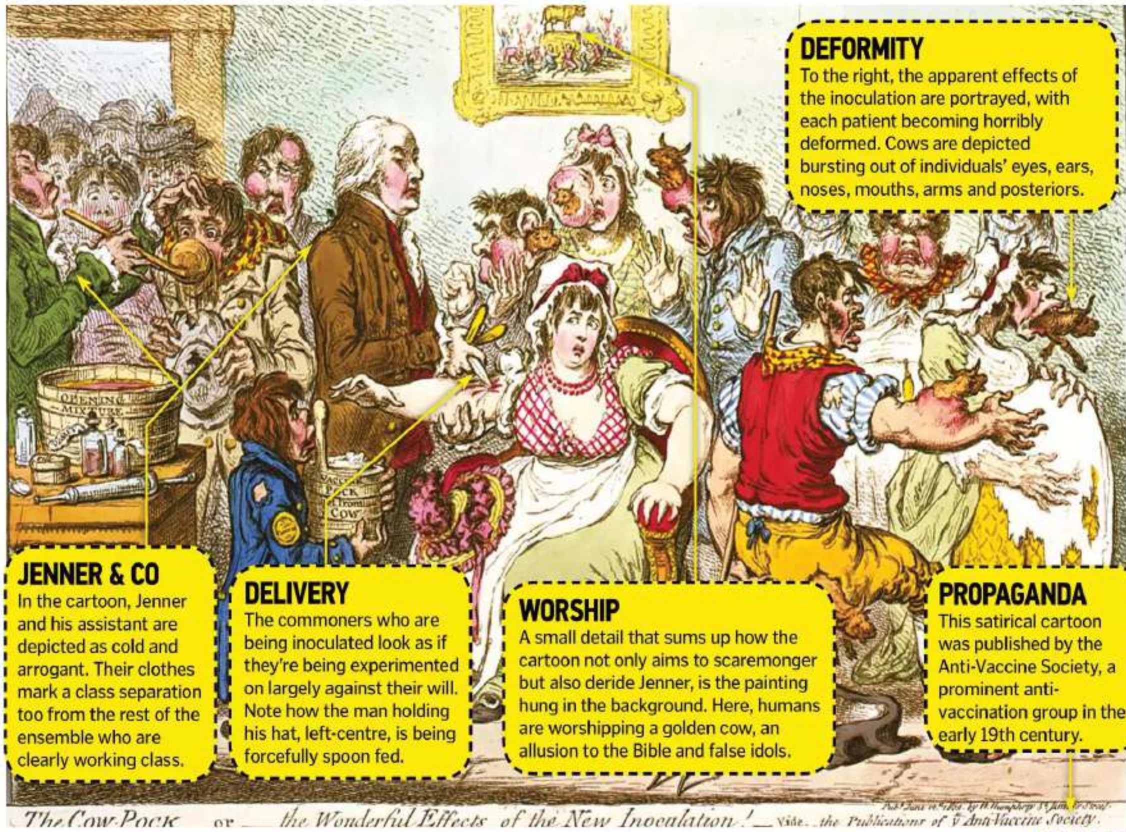
1500 BCE
The Ancient Egyptians bring smallpox over to Egypt from India and China. The virus proceeds to take hold, claiming many lives including, most probably, that of Pharaoh Ramesses.

700 CE
Arab armies carry the smallpox virus out of Africa and into Europe throughout the 7th and 8th centuries. The following Crusades continue this transference, leading to its widespread establishment in Europe.

1585
Book XII of the 16th-century Florentine Codex – an ethnographic research project carried out in Mesoamerica – details how the native Nahua people of Mexico suffer greatly from smallpox (right).

THE VACCINATION WAR

WHILE JENNER'S BREAKTHROUGH IS OBVIOUS FROM A MODERN PERSPECTIVE, THE IDEA OF INJECTING PEOPLE WITH ONE VIRUS TO PROTECT AGAINST ANOTHER CAUSED GREAT CONTROVERSY IN HIS TIME



DEFORMITY
To the right, the apparent effects of the inoculation are portrayed, with each patient becoming horribly deformed. Cows are depicted bursting out of individuals' eyes, ears, noses, mouths, arms and posteriors.

JENNER & CO
In the cartoon, Jenner and his assistant are depicted as cold and arrogant. Their clothes mark a class separation too from the rest of the ensemble who are clearly working class.

DELIVERY
The commoners who are being inoculated look as if they're being experimented on largely against their will. Note how the man holding his hat, left-centre, is being forcefully spoon fed.

WORSHIP
A small detail that sums up how the cartoon not only aims to scaremonger but also deride Jenner, is the painting hung in the background. Here, humans are worshipping a golden cow, an allusion to the Bible and false idols.

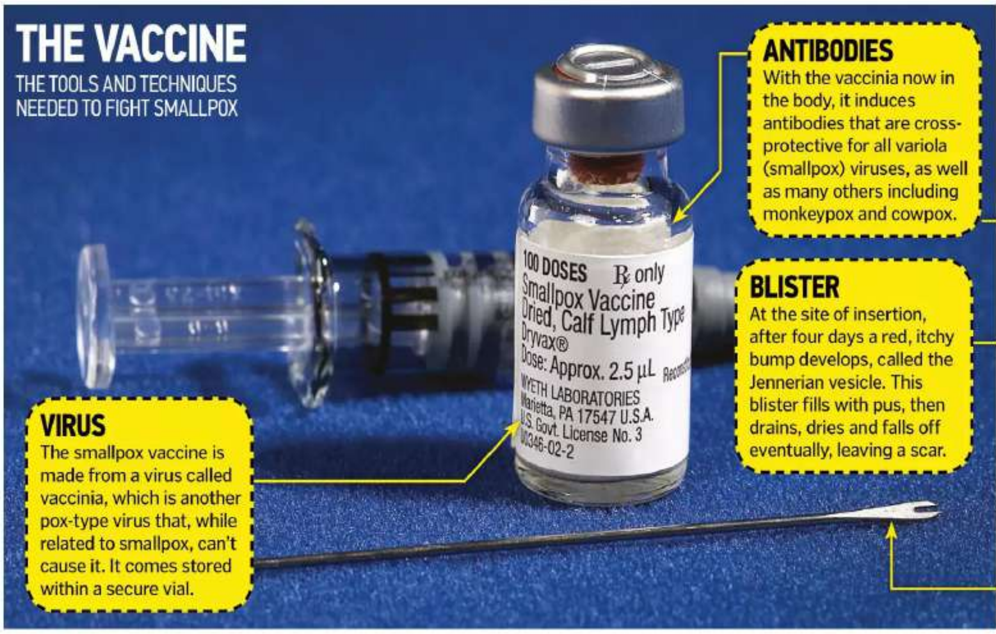
PROPAGANDA
This satirical cartoon was published by the Anti-Vaccine Society, a prominent anti-vaccination group in the early 19th century.

BIRTHPLACE OF THE CURE TO SMALLPOX

Edward Jenner's house, the place where he undertook the most important work in his formulation of the vaccination against smallpox, still stands today. Located in the town of Berkeley, Gloucestershire, the house is now the Edward Jenner Museum, which combines a traditional museum with an interactive learning environment for children and a historical archive. For more information, readers can visit www.jennermuseum.com.

THE VACCINE

THE TOOLS AND TECHNIQUES NEEDED TO FIGHT SMALLPOX



ANTIBODIES
With the vaccinia now in the body, it induces antibodies that are cross-protective for all variola (smallpox) viruses, as well as many others including monkeypox and cowpox.

BLISTER
At the site of insertion, after four days a red, itchy bump develops, called the Jennerian vesicle. This blister fills with pus, then drains, dries and falls off eventually, leaving a scar.

VIRUS
The smallpox vaccine is made from a virus called vaccinia, which is another pox-type virus that, while related to smallpox, can't cause it. It comes stored within a secure vial.

PRICKING
The vaccinia solution is inserted by a series of quick, shallow pricks into the surface of the skin (usually on the arm). This causes a sore spot and draws a little blood.

NEEDLE
The smallpox vaccine is not delivered with a hypodermic syringe. Instead it is delivered using a bifurcated (two-pronged) instrument. The needle is designed this way so that it holds a droplet of solution each time.

1796
Edward Jenner realises that people infected with the non-fatal cowpox disease cannot catch any variant of smallpox. He proceeds to run a series of successful trials, creates the world's first vaccine and publishes his findings. He receives a very mixed reaction though.

1966
The Centers for Disease Control and Prevention (CDC) in Georgia, USA, launches a campaign promoting the importance of smallpox and measles vaccinations. A series of posters is created and distributed globally.

1975
The last known person to have been infected with the naturally occurring variola major smallpox strain is treated. Rahima Banu Begum (right) fully recovers and is still alive today with four children.

1980
Thanks to Edward Jenner, numerous other scientists and organisations such as the CDC, smallpox is eradicated totally in 1980. Today, small stocks of the virus are kept in a few highly secure laboratories.

MEDICAL DEVICES

THESE TORTUROUS-LOOKING INSTRUMENTS AND MACHINES WERE ACTUALLY DESIGNED TO SAVE LIVES!

TREPAN

6500 BCE, EUROPE

These days, if we have a headache we can take an aspirin, have a glass of water, and it usually disappears within an hour or two. But in Neolithic times, the cure was a lot more gruesome. A hole was cut in the skull of the patient to expose the dura mater - the brain's tough outer layer. This was done using a trepan, which in Neolithic times was simply a piece of flint attached to a wooden shaft. In some parts of the globe, trepanning is still used today to treat mental disorders.

Neolithic trepans were made from flint or shark's teeth

Speculums barely diverged from this Roman design until the 20th century

ABU AL-QASIM AL-ZAHRAWI

936-1013, ARAB

Al-Zahrawi devoted his life to the advancement of medicine. He was an advocate of cauterisation and introduced over 200 surgical instruments, including forceps - drastically decreasing the infant mortality rate. He was also the first physician to describe an ectopic pregnancy and the first to identify the hereditary nature of haemophilia.

IRON LUNG

1928, USA

These were among the first life-support machines, gaining fame for saving polio victims whose breathing muscles had been paralysed by the disease. They consisted of an airtight chamber connected to an air pump. Air was sucked in and out of the chamber, causing the patient's lungs to contract and expand, allowing them to breathe. Many polio patients recovered after spending only minutes inside an iron lung, while other less fortunate victims spent their entire lives looking at the world through a mirror attached to the top of the machine.

The first iron lung was made from parts of vacuum cleaners

SPECULUM

79 CE, ITALY

Though the eruption of Mount Vesuvius destroyed the lives of thousands of Roman people, the artefacts recovered from the ash-covered city of Pompeii provide a never-before-seen insight into the lives they led. This includes medicine. Several surgical instruments have been found here, including this terrifying-looking speculum. Roman gynaecology was relatively primitive, and physicians even believed that a woman's womb could 'wander' around the body, wreaking havoc on her internal organs and causing hysteria.

"RATHER THAN TREAT A TOOTHACHE WITH ANTIBIOTICS, INFECTED TEETH WOULD HAVE TO BE PULLED OUT USING A DENTAL KEY"

OSTEOTOM

1830, GERMANY

In the days before general anaesthetics, amputations were incredibly painful and incredibly dangerous. Bones were often splintered and the tissue around them was damaged by the harsh impact of a hammer and chisel or the jolts of a saw. Surgeons needed to find a way to speed up the procedure and reduce the risk of complications. The solution came in the form of the osteotome - a device with a chain and sharp cutting teeth that was cranked manually. What this device was, in fact, was the first-ever chainsaw.

The chain carried sharp teeth that could easily cut through hard bone

This 16th-century bullet extractor was made of steel and had ornate handles

BULLET EXTRACTOR

16TH CENTURY, EUROPE

The introduction of firearms to the battlefield in the early 13th century changed the face of warfare. Until the invention of this revolutionary device, only bullets close to the surface of the skin could be removed. This bullet extractor allowed surgeons to dig much deeper. It consisted of a hollow rod containing a screw, which could be lengthened or shortened using the handle at the top. The instrument was placed in the wound and the screw lengthened in order to pierce the bullet and remove it.

AMBROISE PARÉ

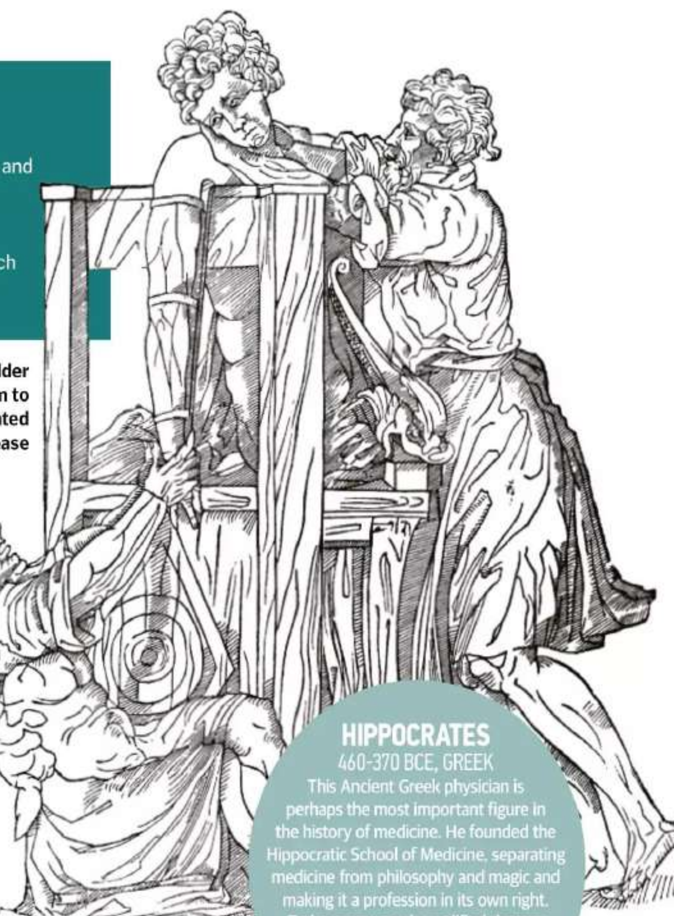
1510-1590, FRENCH

A barber surgeon - doctor who treated soldiers on the battlefield - he served a number of French kings. He is considered a pioneer in surgical techniques and battlefield medicine, having discovered it was better to treat wounds with turpentine than cauterising them. He also invented several instruments and prostheses, including artificial eyes.

REDUCTION DEVICE

5TH CENTURY BCE, GREECE

Hippocrates is considered the father of Western medicine and he detailed the oldest known method for treating a dislocated shoulder. He developed a ladder-like device, across which the injured arm was slung and then pulled downward with significant force. In the 16th century, French royal surgeon Ambroise Paré reintroduced Hippocrates' method, and it is still used today.



Hippocrates' ladder allowed him to relocate a dislocated shoulder with ease

LITHOTOME

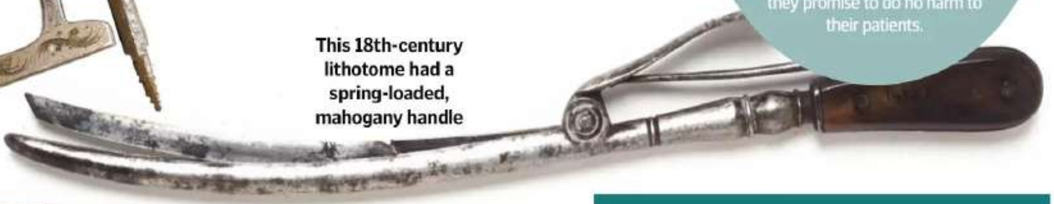
1780, BRITAIN

This long, claw-like instrument was inserted up the urethra and into the bladder. The surgeon would then use it to grip onto small bladder stones and pull them out, or use the blade to cut up larger ones so they could be weed out. This all happened while the patient was awake - undoubtedly in a lot of pain! The surgeon also had to make sure they didn't slice the bladder in the process, or the patient may have bled to death.

HIPPOCRATES

460-370 BCE, GREEK

This Ancient Greek physician is perhaps the most important figure in the history of medicine. He founded the Hippocratic School of Medicine, separating medicine from philosophy and magic and making it a profession in its own right. Today, many newly qualified doctors take the Hippocratic Oath, in which they promise to do no harm to their patients.



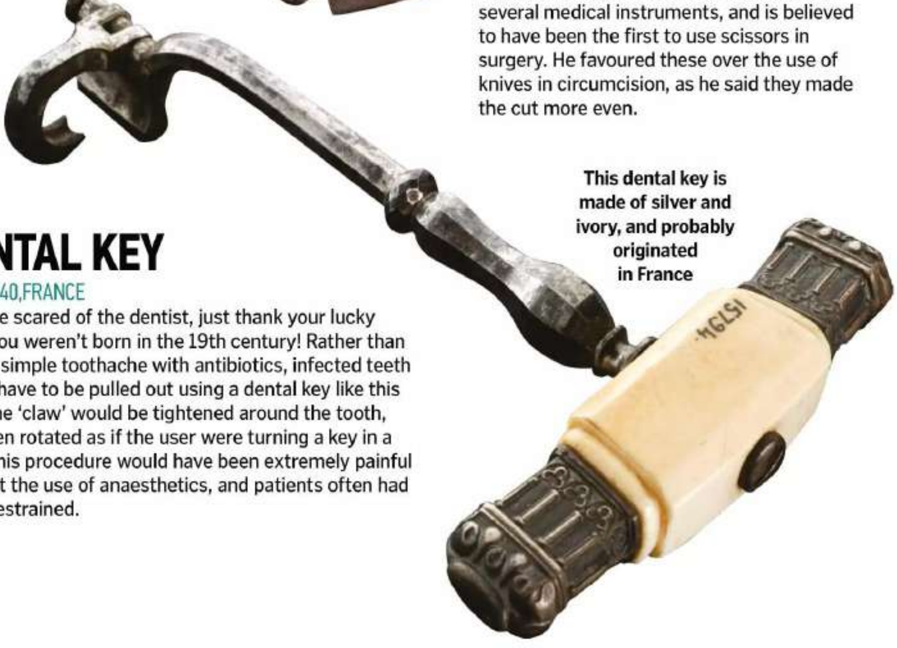
This 18th-century lithotome had a spring-loaded, mahogany handle

Al-Zahrawi revolutionised how surgery was performed with the invention of many new tools

CIRCUMCISION SCISSORS

10TH/11TH CENTURY, MUSLIM SPAIN

Medieval surgeon Abu al-Qasim al-Zahrawi transformed circumcision from a religious ritual to a surgical procedure. He invented several medical instruments, and is believed to have been the first to use scissors in surgery. He favoured these over the use of knives in circumcision, as he said they made the cut more even.



This dental key is made of silver and ivory, and probably originated in France

DENTAL KEY

1800-1840,FRANCE

If you're scared of the dentist, just thank your lucky stars you weren't born in the 19th century! Rather than treat a simple toothache with antibiotics, infected teeth would have to be pulled out using a dental key like this one. The 'claw' would be tightened around the tooth, and then rotated as if the user were turning a key in a lock. This procedure would have been extremely painful without the use of anaesthetics, and patients often had to be restrained.

Newer CT scanners can produces 3D images of our insides

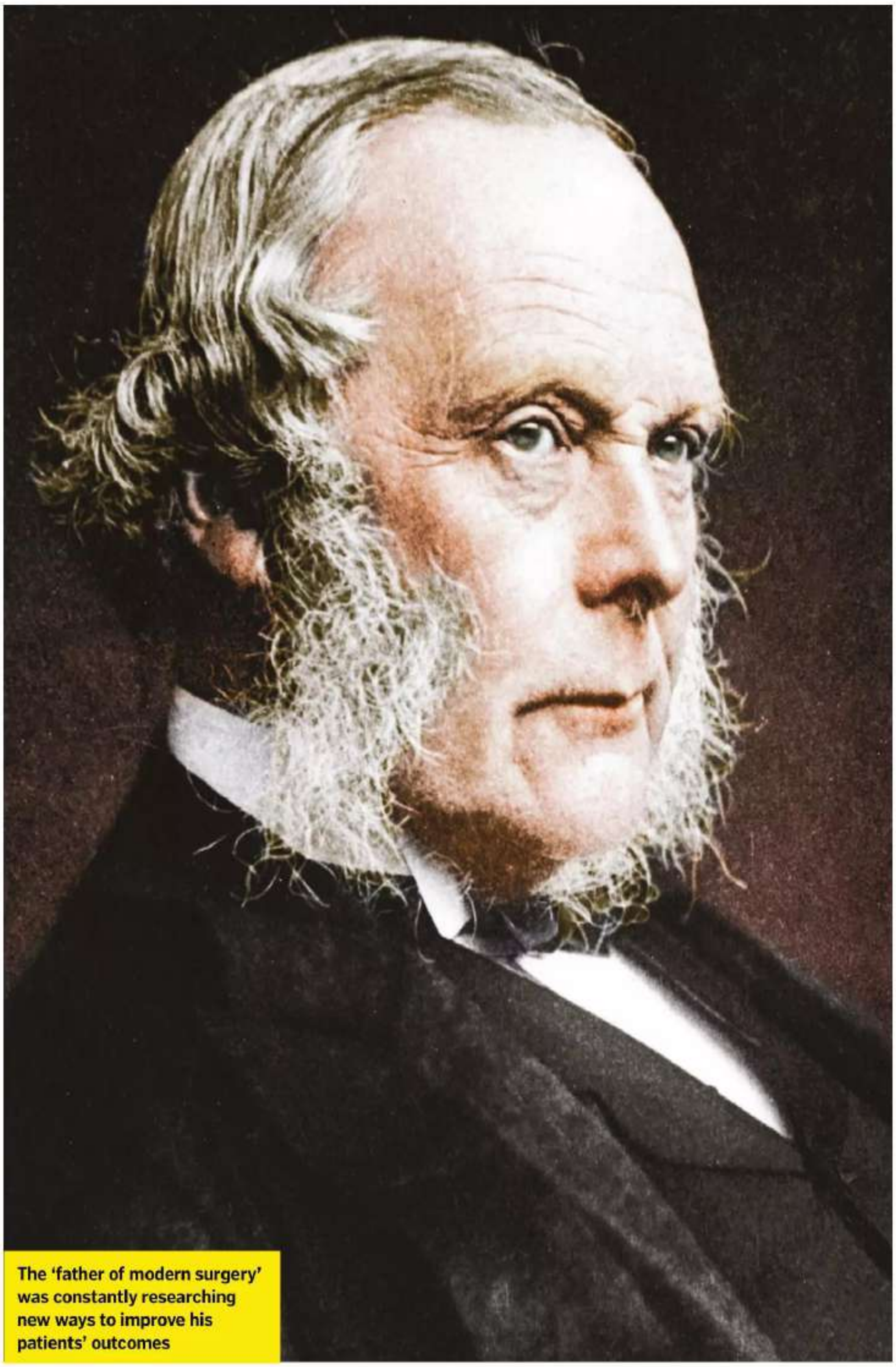
CT SCANNER

PRESENT, BRITAIN

The pinnacle of modern medicine, the CT scanner allows doctors to see detailed images of our insides. It was originally designed to take pictures of the brain, and the first time it was used in 1971 it revealed a brain tumour in a 41-year-old patient. Now doctors can use them to detect all kinds of abnormalities in any part of the body. It works by beaming X-rays through the patient, which are then received by the machine and the information sent to a computer. This then processes the information to create an image.

ANTISEPTICS IN SURGERY

MEET THE MAN WHO INVENTED THE METHOD THAT MADE SURGERY SAFER



The 'father of modern surgery' was constantly researching new ways to improve his patients' outcomes

Joseph Lister was born into a Quaker family on 5 April 1827. Having spent his childhood dissecting specimens and looking at tissue samples using his father's microscope, the young Lister decided to become a surgeon. Despite his interest in comparative anatomy, he completed an arts degree at University College London (a secular alternative to Oxbridge). He eventually did go on to study medicine in 1848, graduating with several different honours and gold medals.

At this time surgery was developing as a speciality, with the introduction of proper training and the use of general anaesthetics. In December 1846, Lister witnessed the first use of ether anaesthetic in England. But, many patients still died after their operations from infection. People believed this was caused by poisonous air, or 'miasma'. Surgeons often arrived in theatre straight from dissecting dead bodies and didn't consider washing their hands between patients. They took pride in the 'good old surgical stink' of their unwashed operating gowns.

"WHEN HE PUBLISHED HIS FIRST RESULTS IN 1867, THERE WAS CONSIDERABLE OPPOSITION"

In 1853, Lister travelled to Edinburgh to learn from Professor James Syme, where he would transform the future of medicine. Three years later, Lister married Syme's daughter Agnes, who would help him with much of his research.

By the age of 33, Lister had become professor of surgery at the University of Glasgow. He was a popular lecturer, known for making students laugh and investing his own money in a lecture theatre more suited to learning. However, he was still frustrated by the high levels of infection

A LIFE'S WORK

HOW A STUDIOUS BOY BECAME THE FATHER OF MODERN SURGERY

1827
Joseph Lister is born in Upton, Essex, to Quaker parents Isabella Harris and Joseph Jackson Lister, the fourth of their seven children.

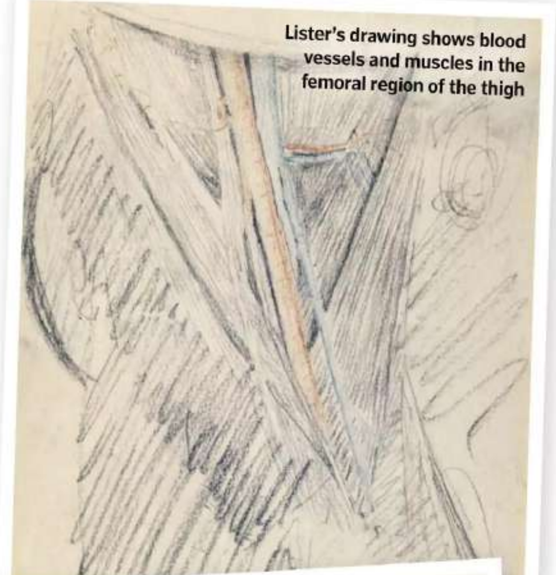
Teenage years
Lister knew he wanted to be a surgeon early on. He spent a lot of time drawing bodies and dissecting animals.

1847
Graduates with an arts degree from University College, London. His father encouraged him having a rounded education.

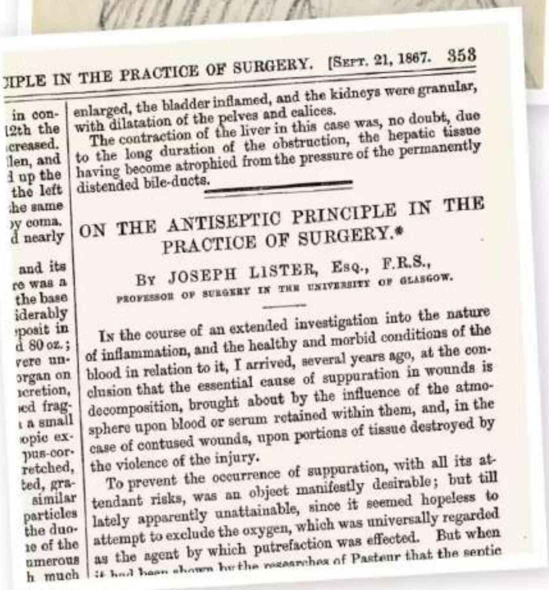
1852
Graduates with a bachelors in medicine and becomes a fellow of the Royal College of Surgeons.

1853
Moves to Edinburgh to learn from James Syme, one of the greatest surgical teachers at the time, in Europe.

1856
Marries Agnes Syme, Syme's bright daughter. Agnes assists him with his experiments.



Lister's drawing shows blood vessels and muscles in the femoral region of the thigh



IPLE IN THE PRACTICE OF SURGERY. [SEPT. 21, 1867. 353

enlarged, the bladder inflamed, and the kidneys were granular, with dilatation of the pelves and calices.

The contraction of the liver in this case was, no doubt, due to the long duration of the obstruction, the hepatic tissue having become atrophied from the pressure of the permanently distended bile-ducts.

ON THE ANTISEPTIC PRINCIPLE IN THE PRACTICE OF SURGERY.*

BY JOSEPH LISTER, ESQ., F.R.S.,

PROFESSOR OF SURGERY IN THE UNIVERSITY OF GLASGOW.

IN the course of an extended investigation into the nature of inflammation, and the healthy and morbid conditions of the blood in relation to it, I arrived, several years ago, at the conclusion that the essential cause of suppuration in wounds is decomposition, brought about by the influence of the atmosphere upon blood or serum retained within them, and, in the case of contused wounds, upon portions of tissue destroyed by the violence of the injury.

To prevent the occurrence of suppuration, with all its attendant risks, was an object manifestly desirable; but till lately apparently unattainable, since it seemed hopeless to attempt to exclude the oxygen, which was universally regarded as the agent by which putrefaction was effected. But when

The Antiseptic Principle of the Practice of Surgery, published in the Lancet in 1867

on his wards. Other surgeons were using various antiseptics to treat infected wounds with limited success.

Building on the work of Louis Pasteur, Lister's revolutionary approach was to use diluted carbolic acid (now known as phenol) before infection set in. He first tested it on patients with broken bones where the injuries were open to the air. He and his assistants washed their hands and instruments in carbolic acid before applying it to the site of the injury. Eight out of ten of his first patients fully recovered. Encouraged, he began using the system for operations.

When he published his first results in 1867, there was considerable opposition. He was seen by some as a dangerous charlatan, but Lister was undeterred. Gradually, his principles were adopted. In 1869, he left Glasgow to replace his father-in-law as professor of clinical surgery in Edinburgh. He would later develop a new method of fixing broken kneecaps with wire.

Towards the end of his life he was honoured with many awards, including a knighthood and elevation to the House of Lords as Lord Lister of Lyme Regis. He became Queen Victoria's personal surgeon as well as one of her privy counsellors. He was also elected president of the Royal Society, following in the footsteps of Sir Isaac Newton. In the midst of this, he helped found what is now the Lister Institute of Preventive Medicine in Hertfordshire, UK.

HOW LISTER BUILT ON LOUIS PASTEUR'S WORK TO REVOLUTIONISE SURGERY

After reading Pasteur's work, Lister became convinced that infection was caused by germs, not the surrounding 'bad' air. He soon began searching for an ideal antiseptic.

He knew sewage plant engineers used carbolic acid to conquer the smell from rubbish and nearby fields irrigated with liquid waste. It was noted that the cows grazing there were no longer getting a disease known as 'cattle fever'.

Lister used these facts to develop a system where surgeons and assistants washed their hands and instruments and cleaned the wound with carbolic acid to prevent infection. This reduced the number of post-operative deaths from around 50 per cent to 15 per cent - a remarkable reduction at this time.

Lister was the first to use antiseptics during surgery to prevent infection before it developed

1860
Becomes professor of surgery at the University of Glasgow and visiting surgeon at Glasgow Royal Infirmary in 1861.

1867
Having spent two years developing his methods, Lister publishes his revolutionary work on antiseptics.

1897
Elevated to the peerage as Lord Lister of Lyme Regis, one of many honours he receives following widespread acceptance of his ideas.

1912
Lister dies in Walmer, Kent, aged 84. His funeral service is held at Westminster Abbey and he is buried at West Hampstead Cemetery.

5 THINGS TO KNOW ABOUT... JOSEPH LISTER

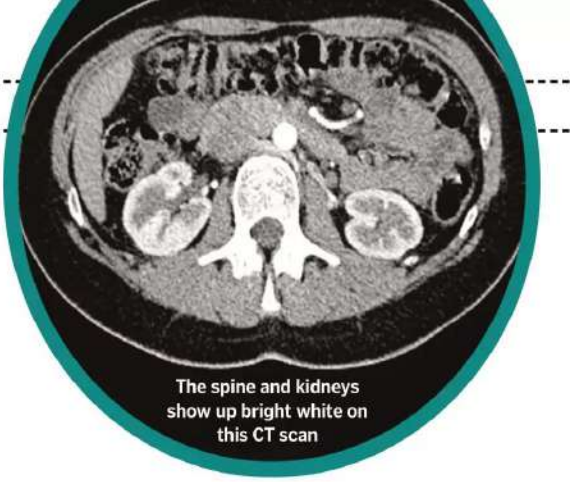
1 SCIENCE RAN IN THE LISTER FAMILY His father left school at the age of 14, but was later internationally recognised for his work improving the compound microscope with his achromatic lens design.

2 HE DESIGNED SURGICAL INSTRUMENTS
Lister's patents included a needle for stitching wounds, a hook to pull objects out of the ear and a tourniquet for the abdominal aorta, the largest artery in the body.

3 HIS SYSTEM WAS INTERNATIONALLY ADOPTED
While there was still opposition to his antiseptic system in the UK, French and German doctors were using it to treat casualties in the Franco-Prussian War.

4 HE WAS A CARING DOCTOR
Lister referred to patients as 'this poor man' or 'this good woman' instead of 'cases'. He taught students to use technical words when discussing their care to avoid frightening them.

5 HE ALMOST BECAME A PREACHER
At one point during his studies, Lister decided to abandon surgery and become a preacher instead, but his father managed to persuade him against the idea.



The spine and kidneys show up bright white on this CT scan

COMPUTERISED TOMOGRAPHY

THESE 3D X-RAYS CAN CREATE DETAILED PICTURES OF THE INSIDE OF YOUR BODY

At the end of the 19th century, Wilhelm Röntgen discovered X-rays and changed medicine forever. As X-rays pass through the body, different tissues absorb different amounts of energy, leaving shadows on photographic film. For the first time, doctors could see inside their patients without having to cut them open. But the story didn't stop there.

If you capture one X-ray image you see a snapshot of the body, but with the organs piled on top of one another it's hard to make out what's going on. In 1972, Godfrey Hounsfield found a solution when he invented computerised tomography (CT) scans, thereby revolutionising medicine again.

CT scanners use a rotating ring to take X-ray images from all angles. A computer then combines these images to separate out the signals from different bones, organs and blood vessels. This creates image slices between one and ten millimetres thick, showing the inside of the body in cross-section. During the scan, a table slides the patient through the ring, capturing more and more image slices. Then the computer stacks them together to make 3D pictures of the internal organs.

The result is a much higher-resolution picture of the inside of the body. The outlines of the tissues are clearer than a normal X-ray, and the 3D shapes allow medical professionals to see abnormalities. X-ray-absorbing chemicals called contrast agents can make the pictures even clearer. For example, iodine injected into the blood can reveal the outline of the blood vessels, showing up clots. Barium swallowed in a meal or drink can highlight the outline of the digestive system, revealing tumours.

Though X-rays do deliver small amounts of ionising radiation, which can damage cells, the benefits far outweigh the risks.

INSIDE A CT SCANNER

PATIENTS SLIDE THROUGH A ROTATING RING STUFFED WITH X-RAY TECHNOLOGY

CT VS MRI

CT scans are good for showing up bones, blood vessels and organs, but they can't capture the fine detail of soft tissues. To do this we need magnetic resonanceimaging (MRI). These scans use a combination of radio waves and powerful magnets to make 3D pictures. The magnets pull on the hydrogen atoms in the water molecules inside the body, rotating them so they all point in the same direction. Radio waves then knock them temporarily out of line; when they snap back in line, they release energy. Detectors pick this energy up, creating a picture of where the water molecules are. Different tissues contain different amounts of water, giving a clearer view of the internal organs.

MRI scans offer a higher-resolution picture of the body's soft tissues

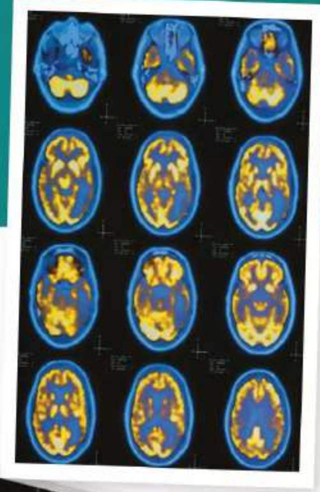
PET AND SPECT

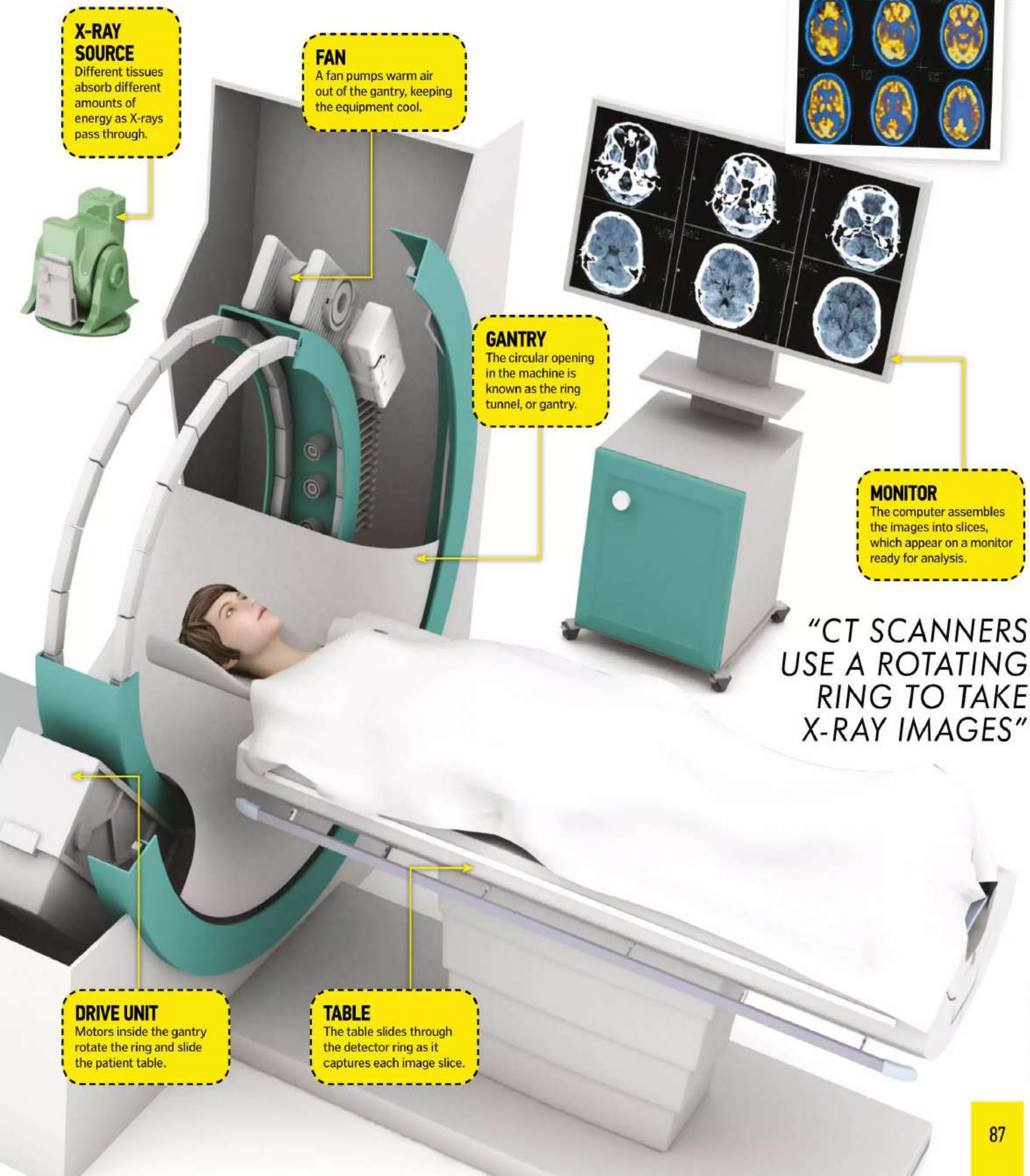
Doctors can zone in on specific parts of the body using nuclear medicine. This involves injecting, inhaling or swallowing small amounts of radioactive material to light up different tissues.

Doctors sometimes need to highlight the blood vessels to look for circulation problems. To do this they can use single photon emission computed tomography (SPECT) scans. Patients receive an injection containing radioactive atoms, which enter the blood and release gamma rays as they circulate. When a gamma camera detects the rays, it reveals the outline of the blood vessels.

Another option is a positron emission tomography (PET) scan. These use radioactive tracers that produce positrons instead of gamma rays. Positrons interact with electrons inside the body, sending bursts of energy to the detectors. PET tracers attached to sugar molecules can light up tissues using lots of energy, like active areas of the brain or growing tumours.

The yellow areas of the brain on this PET scan are using the most energy





"CT SCANNERS USE A ROTATING RING TO TAKE X-RAY IMAGES"

TECHNOLOGY

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THE RADIO

SOMETIMES CALLED THE FATHER OF RADIO, GUGLIELMO MARCONI'S PRACTICAL TELEGRAPHY SYSTEM LED TO THE WIDESPREAD USE OF WIRELESS COMMUNICATIONS

Marconi developed his radio equipment in the attic of his parents' home in Italy with the help of his butler, Mignani

"THE MARCONI ROOM ABOARD THE RMS TITANIC AND ITS TWO MARCONI WIRELESS OPERATORS TRANSMITTED THE MOST FAMOUS RADIO SIGNALS OF ALL TIME"

Guglielmo Giovanni Maria Marconi was a famous and widely respected Italian inventor who pioneered the development of wireless communication and long-distance radio transmission. Often credited as the inventor of the radio, Marconi was actually an astute businessman who combined, and built upon, the work of other scientists in his bid to develop a commercially viable method of long-distance communication.

Marconi's interest in electricity and physics began at an early age, and he was inspired by the work of scientists like James Clerk Maxwell, Heinrich Hertz and Nikola Tesla, among others. In 1894, he read the work of German physicist Hertz, who had developed equipment to send and detect electromagnetic waves over short distances. Marconi saw the potential for transmitting information using radio waves and set about developing a longer-range system to replace wire-based telegraphy.

Marconi began his experiments at his father's estate and with the help of his butler, Mignani, built equipment in the attic. Soon he could transmit radio waves over short distances, so he moved his experiments outdoors to develop the technology further. He found that increasing the length of the antennas – and arranging them vertically – increased the range of transmission so much that he was able to send and receive signals over distances of around 2.4 kilometres.

It was at this point that Marconi began to see the potential commercial applications of his experiments. Italy already had a well-established telegraph system though, with networks of wires extending across the country, and his applications for funding were dismissed. Undeterred, Marconi travelled to the UK. Britain had a powerful Royal Navy and was the world's greatest trading empire, and his thinking was that they might have use for his work in maritime communication. Marconi managed to gain the support of the engineer-in-chief of the

A LIFE'S WORK

TUNE IN TO SOME OF THE MAJOR EVENTS FROM THE LIFETIME OF THIS ASTUTE ITALIAN RADIO PIONEER

1874
Guglielmo Marconi is born in Bologna, Italy, to landowner Giuseppe Marconi and his Scots-Irish wife Annie Jameson.

1894
Begins to develop a method of transmitting telegraph messages without wires, using radio waves.

1896
Travels to London, where he gains the support of engineer-in-chief of the Post Office, William Preece.

1899
Sets up the first wireless link between Britain and France from Wimereux, France, to a lighthouse in Dover, England.

1900
Takes out his No. 7777 'Improvements in Apparatus for Wireless Telegraphy' patent to protect his technological developments.

Post Office engineers inspect Marconi's radio equipment before the first-ever transmission of radio signals over the open sea

British Post Office and, with his help, demonstrated his technology to the British government. During his first few years in England he gradually improved the distance of radio transmission – first on land and then over sea. His work excited the international community and stations were set up in France for the first radio crossing of the Channel.

As his technology continued to evolve, 'Marconi rooms' were installed in ships, containing a suite of wireless telegraphy equipment which enabled communication with land as well as other vessels. The Marconi room aboard the RMS Titanic and its two Marconi wireless operators transmitted perhaps the most famous radio signals of all time: 'CQD CQD SOS Titanic position 41.44 N 50.24 W. Require immediate assistance. Come at once. We struck an iceberg. Sinking.'

Marconi died in Rome in 1937 at the age of 63. He was given a state funeral and – as a tribute to his massive contribution to wireless communication – every radio station in the world fell silent for two minutes.

"MARCONI BEGAN TO SEE THE POTENTIAL COMMERCIAL APPLICATIONS OF HIS EXPERIMENTS"

THE BIG IDEA

Marconi combined and modified the inventions of other scientists to develop equipment that could transmit radio waves over great distances. He used a spark-gap transmitter to generate radio frequency electromagnetic waves and a coherer receiver to detect them. A telegraph key enabled him to send radio waves in bursts, generating Morse code. Marconi discovered that the maximum distance of radio wave transmission varied according to the square of the height of the transmitting antenna – tall, vertical antennas were key.

FIVE FACTS: GUGLIELMO MARCONI

1 ROYAL CONNECTIONS

Marconi installed radio equipment on Queen Victoria's royal yacht so that she could communicate with the Prince of Wales, the future Edward VII, while travelling.

2 EDUCATED BUT UNQUALIFIED

Marconi had no formal scientific qualifications, but he did have a keen interest in physics. At the request of his mother, he was mentored by physicist Professor Augusto Righi, who introduced him to radio waves.

3 ARE YOU READY?

The first wireless radio transmission to be sent across the open sea was sent on 13 May 1897 over the Bristol Channel. The message travelled a distance of just 6.4 kilometres and read: "Are you ready?"

4 HIGH-SPEED MORSE

To be employed as a wireless operator by Marconi's Wireless Telegraph & Signal Company, you had to be able to send and receive Morse code at a speed of 25 words per minute.

5 LUCKY ESCAPE

Marconi was offered free passage on the famous doomed ship RMS Titanic, but decided to travel to America three days earlier on the RMS Lusitania because he had paperwork to do.

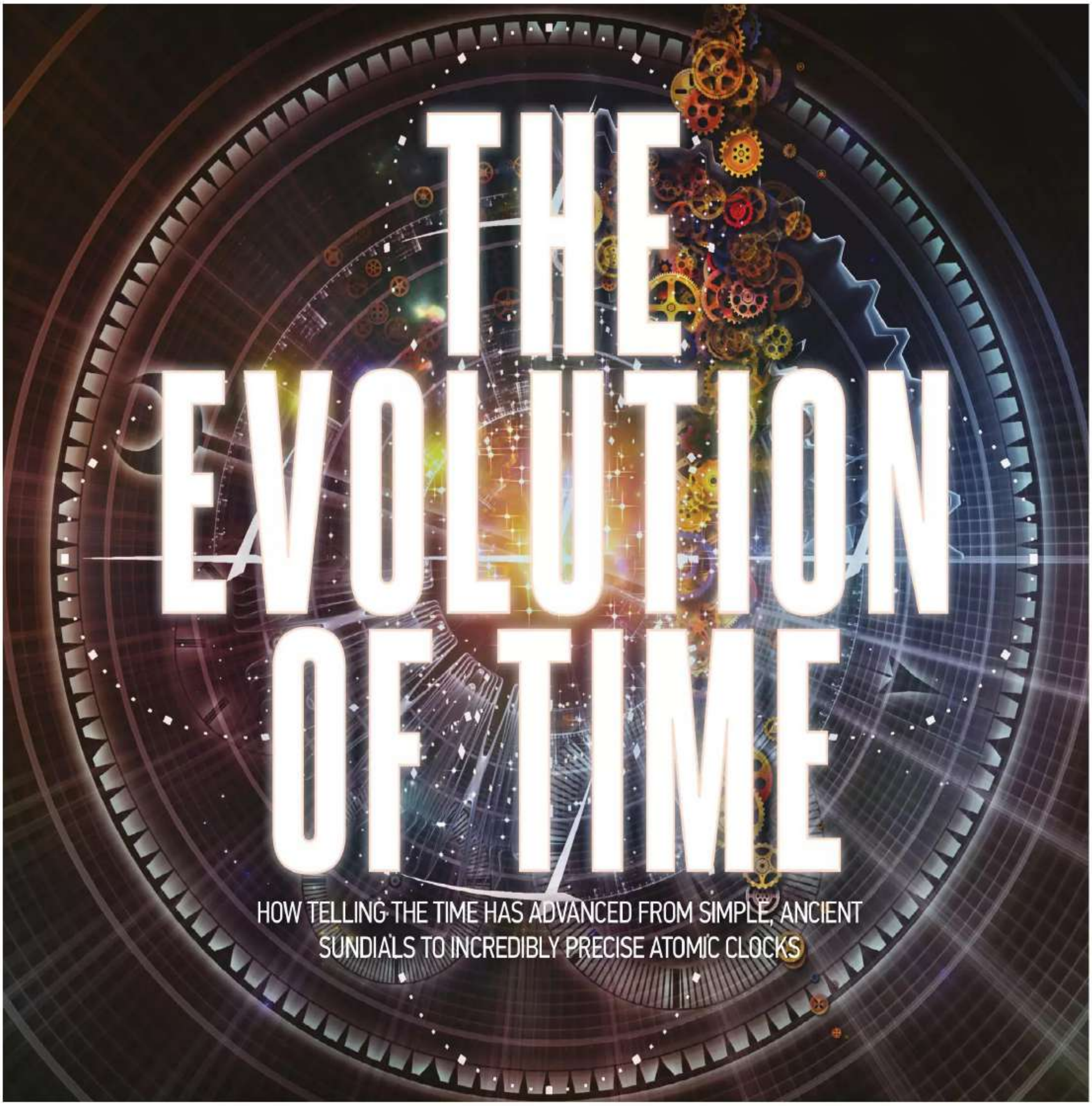
1901
Successfully transmits the letter 'S' in Morse code 3,380 kilometres across the Atlantic Ocean to Newfoundland.

1909
Receives the Nobel Prize in Physics – along with Karl Ferdinand Braun – for their contribution to wireless telegraphy.

1912
Marconi radio is used to save victims of the Titanic, and passes distress signals from the sinking ship to the RMS Carpathia.

1914
Joins the Italian war effort during World War I, where he takes charge of the military's radio service.

1937
Marconi dies aged 63. He receives a state funeral in Italy and all radio stations hold a two-minute silence in his honour.



THE EVOLUTION OF TIME

HOW TELLING THE TIME HAS ADVANCED FROM SIMPLE, ANCIENT SUNDIALS TO INCREDIBLY PRECISE ATOMIC CLOCKS

Just before midnight on 31 December 2016, the world gained an extra second to compensate for the fact that Earth's rotation is ever so gradually slowing down. Modern atomic clocks are too accurate compared to Earth's inconsistent spinning speed, and they tick away at the same rate for millions of years. To ensure our standard time continues to match our atomic clocks – which provide a stable timescale – 26 so-called 'leap seconds' have been added since 1972.

Today, the human race can tell the time with ease and exceptional accuracy, but it wasn't always that simple. At first the only way was to locate the Sun in the sky, and sundials were the first timepieces to appear in ancient civilisations like Egypt, China and Greece. Naturally, with the changing of the seasons altering daylight hours, this system was flawed and various methods were invented to try and tell the time more accurately.

As well as devices, there also needed to be a set numerical system to measure time. The numbers used to calculate time were first theorised by the ancient Sumerians, who devised the sexagesimal system. It's theorised that this was based on counting on their hands, using the thumb of one hand to count the three joints in each of the four fingers to reach 12. Using the five digits on their other hand to tally the counts of 12, this system allowed people to count to 60 using both hands. As 60 is also divisible by many smaller numbers, it was the perfect number to centre on. Another figure that was used and considered important by ancient civilisations was 12, as it was the number of lunar cycles every year. This number is an important one in timekeeping, finding its way into day and night, which are divided up into two 12-hour periods, and the 12 months.

Thus, the standardised idea of time was born and unanimously incorporated (although the French tried to create a ten-hour day with 100-minute-long hours in the late 18th century). But this was only the beginning.

SHADOW CLOCKS

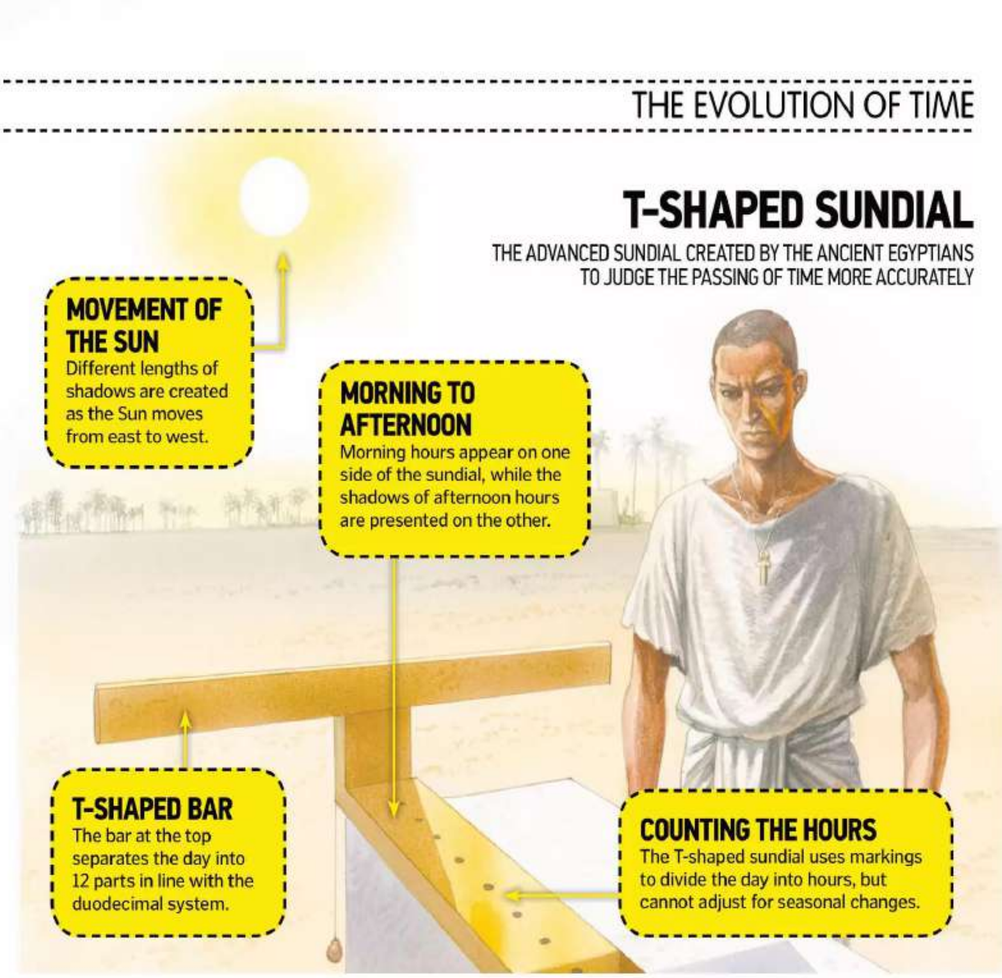
THE SIMPLE YET EFFECTIVE MECHANISMS THAT USED THE SUN TO HELP TO TELL THE TIME

The first timepieces were sticks that measured the length of a shadow to give a rough indication of the time. These sundials became more elaborate and were later developed to point to the nearest pole to be more accurate. They helped divide the day into hours, but were not sophisticated enough to take the weather into account – they were useless at night or on overcast days!

The Egyptians improved on sundials with the invention of the merkhet around 600 BCE, which could be used at night. Lined up with the pole star, the time was measured by known stars crossing the line.

T-SHAPED SUNDIAL

THE ADVANCED SUNDIAL CREATED BY THE ANCIENT EGYPTIANS TO JUDGE THE PASSING OF TIME MORE ACCURATELY



HISTORY OF CALENDARS

MONTHS AND YEARS WERE FIRST DEVISED AFTER ANCIENT CIVILISATIONS GAZED UP AT THE STARS

The Moon has a near 30-day cycle from new to full and to new again. This helped conceive the idea of a month and was the first method that humans used to measure time without using the Sun. Other early markers of time were the beginnings of a rainy season or the appearance of the star Sirius, which in Ancient Egypt coincided with the annual flooding of the Nile.

The next progression was the Julian calendar. Invented by the Romans, it was based on the orbit of the Earth around the Sun. This helped to establish the idea of a year, and so began the Christian calendar. This was not followed in all societies though, and both the Islamic and Jewish calendars are still based on the movement of the Moon, while the ancient Mayan calendar had 18 months of 20 days and one month of five days. The Julian Calendar was later replaced in the UK when the 1750 Calendar Act introduced the more accurate Gregorian calendar.

"THE FRENCH TRIED TO CREATE A TEN-HOUR DAY WITH 100-MINUTE-LONG HOURS IN THE LATE 18TH CENTURY"

PLATO'S ALARM CLOCK

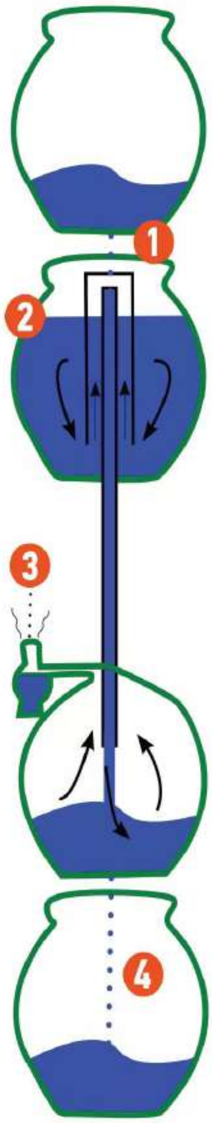
THE FIRST EVER ALARM CLOCK WAS REPORTEDLY INVENTED BY THE FAMOUS GREEK PHILOSOPHER

1. Beginning the process
The mechanism starts with a set amount of water being added to the top jar, which trickles down through the system.

2. Reaching a set level
Once the water reaches a certain level, it is siphoned off into the third jar.

3. Sounding the alarm
The quick influx of water pushes air into the third container that – through a narrow opening – sounds a whistle as a wake up call.

4. Excess water
The bottom jar collects any surplus water, which can be re-used for the next wake-up call.



WATER CLOCKS

The first ever water clock was found in an Ancient Egyptian pharaoh's tomb and is believed to originate from 1500 BCE. The clocks were either cylindrical or bowl-shaped clay containers that worked by measuring water levels. Two designs existed: an inflow model, which measured how much water had filtered out, and an outflow model that calculated how much water remained.

Measurements of hours were marked on the containers. If it took one hour for the water level to drop by a centimetre, then if it dropped by two centimetres, two hours had passed, and so on. The downside was that they couldn't work in cold conditions as the water would freeze, and they needed supervision, as a constant flow of water was required.

The Ancient Greek Tower of the Winds used both a sundial and a water clock called a clepsydra to track the time

MECHANICAL CLOCKS

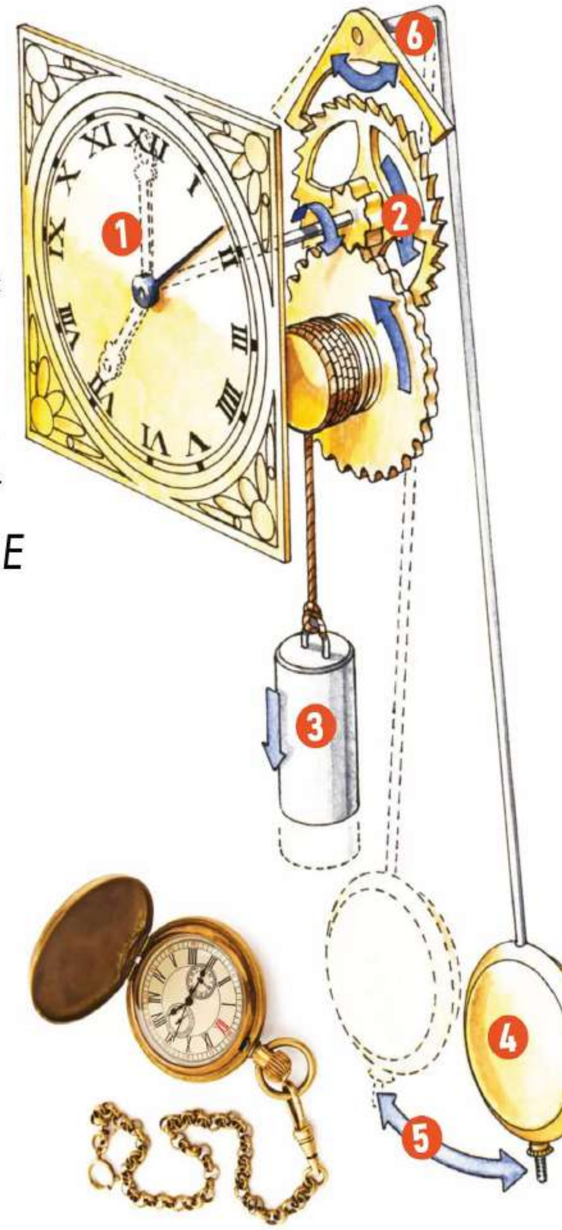
HOW CLOCKWORK BECAME WIDESPREAD AND HELPED CHANGE SOCIETY

The first mechanical clocks only had one hand, but they were much more reliable than previous models. The escapement system they used was possibly invented in China in 1275.

The basic process used springs or weights to work a toothed wheel. However, it could go up to five minutes out of sync per day, and was replaced by the pendulum clock.

Pendulum clocks were first developed by Christiaan Huygens, who was inspired by Galileo's discovery that a pendulum swings at a particular rate depending on its length, making each complete swing in roughly the same period of time.

One of the greatest achievements of mechanical clocks was giving the concept of time to almost all sections of society, not just a select few. Clock faces had appeared in the towers of churches and cathedrals all over Europe by the 14th century, and people could now set proper meal times, bed times and working hours.



"MECHANICAL CLOCKS BROUGHT THE CONCEPT OF TIME TO ALMOST ALL SECTIONS OF SOCIETY"

1. Tick tock
The escapement system alternates with the swing of the pendulum. The horizontal verge and vertical verge work like a seesaw.

2. Counting seconds
A notched wheel turns the gear, which in turn moves the hands at a constant rate. Each tick tock sound represents one second.

3. Weight
A weight powers the mechanism. As it drops, it pulls the second hand around the clock face. These must regularly be raised manually in order to keep the clock running.

4. Pendulum
The pendulum manages the rate of the mechanical clock, based on its regular swinging motion.

5. Energy conversion
The pendulum converts potential energy into kinetic and back again as it swings back and forth. This ensures that a constant motion is maintained.

6. Complementing mechanism
The escapement helps the pendulum work, too. The mechanism helps maintain the pendulum swing so that it is not slowed down by friction or air resistance.

POCKET WATCHES AND WRISTWATCHES

THE FIRST CLOCKS THAT COULD BE CARRIED AROUND AND USED ON THE GO

As clockwork became more compact, spring mechanisms became small enough for portable clocks or watches. The first true pocket watch was invented by Peter Henlein in 1509, who devised a way to create a clock without the need for a pendulum or falling weights. The spring-loaded design was known as the Nuremberg Egg, and while it was very heavy, it quickly became popular.

The next major advancement came when Christiaan Huygens tweaked the design so it now included a minute hand. More wheels within the watch were also added, meaning it had to be wound less frequently. These improved pocket watches fast became essential as conductors used them to help the trains run on time and army generals used them to synchronise orders and missions.

Wristwatches were invented in 1868 by Swiss company Patek Philippe. They were initially only popular with noblewomen, as men preferred to carry pocket watches, but this all changed in World War I.

Soldiers now wore wristwatches to help time artillery barrages and infantry rushes. The masculine image of the troops wearing watches soon caught on at home.

ATOMIC CLOCKS

After the success of quartz clocks, it seemed like there wasn't much more improvement to be made. Then came the atomic clock. First created in 1955, three major types have been made since: caesium, hydrogen and rubidium.

The modern definition of a second is based on the caesium atomic clock. Electrons around a nucleus orbit at set energy levels, but when they absorb or release energy they can 'jump' up or down to the next energy level respectively. Lasers are used to make a caesium atom's electrons move between specific energy levels, so the radiation they emit will always be at the same frequency, which can then be measured.

The results are incredibly precise: the best types are predicted to lose one second in over 50 million years. Atomic clocks form the basis for GPS tech, space mission navigation and the synchronisation of the internet.

QUARTZ CLOCKS

HOW TINY CRYSTALS HELPED MAKE WATCHES AND CLOCKS MORE ACCURATE

Perhaps the biggest jump in timekeeping technology came in the second half of the 20th century with the advent of quartz clocks. Quartz crystals have piezoelectric properties, meaning they can generate an electric current when pressurised and will also vibrate when an electric current is passed through it. These properties were exploited to create quartz clocks and watches.

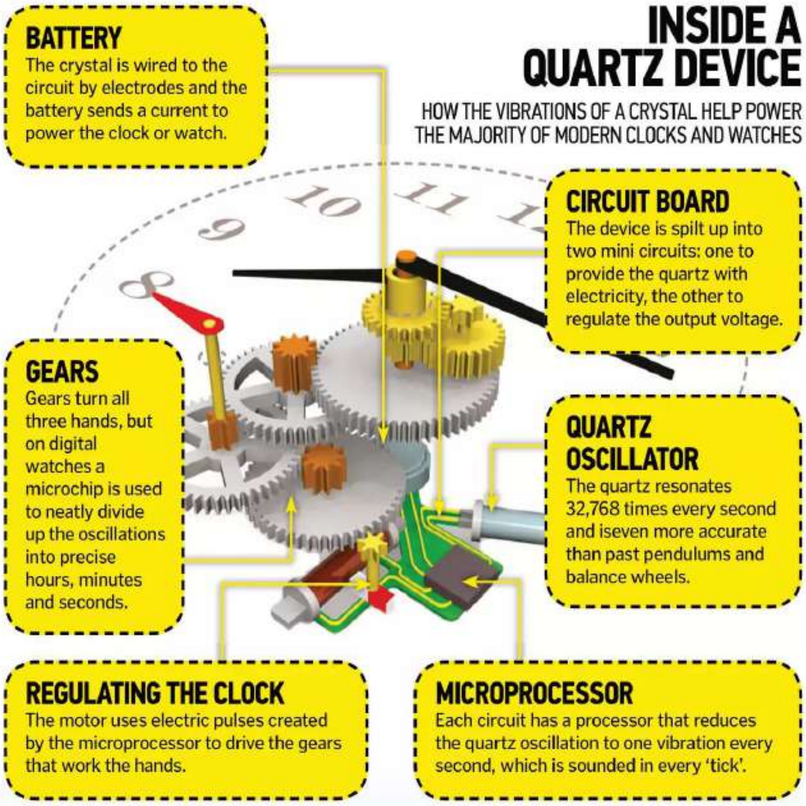
First built in 1927 by Warren Marrison and J W Horton of Bell Telephone Laboratories in New Jersey, US, the quartz clock was operated by a battery feeding a crystal with electricity, which then moved a standard clock face or powered a digital LED display. These new clocks didn't need winding and didn't rely on gravity in order for them to work properly.

The signal emitted by the crystal oscillator was set at a very precise frequency, meaning quartz clocks quickly proved to be at least an order of magnitude more accurate than their mechanical predecessors.

Extremely energy efficient and very reliable, the use of quartz crystals was a turning point in the evolution of clockwork. They are now the world's most widely used clocks.

INSIDE A QUARTZ DEVICE

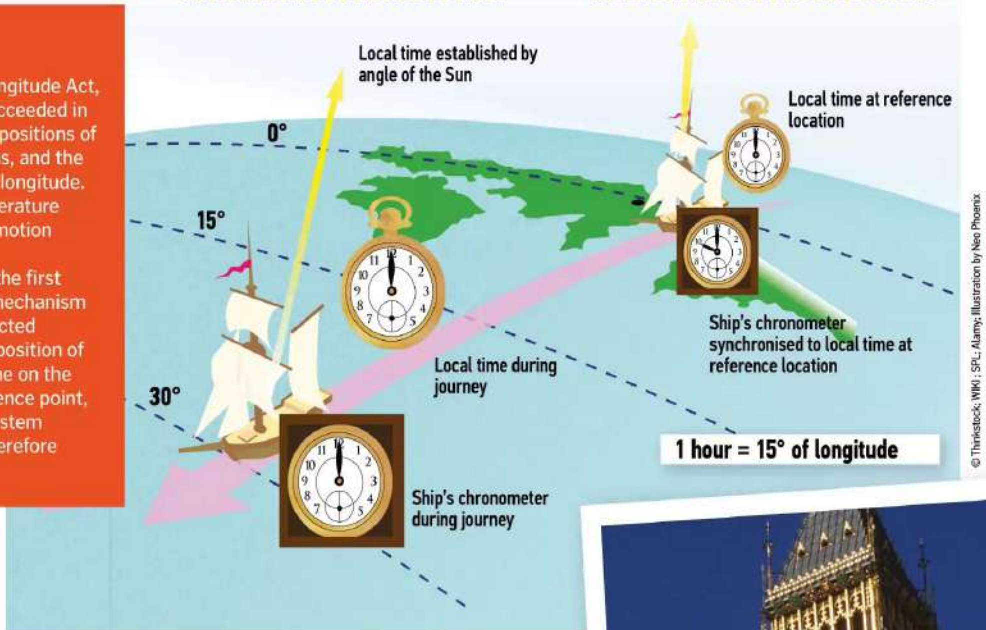
HOW THE VIBRATIONS OF A CRYSTAL HELP POWER THE MAJORITY OF MODERN CLOCKS AND WATCHES



TELLING THE TIME AT SEA

In 1714, the British Government established the Longitude Act, offering a £20,000 reward to any inventor who succeeded in inventing a clock that worked at sea. Knowing the positions of their ships was very important for maritime nations, and the time of day was an important factor in calculating longitude. Accurate timekeeping was difficult at sea as temperature changes, humidity and interference from a ship's motion stopped pendulum clocks working effectively.

John Harrison's H4 device led the way and was the first marine chronometer with a spring and a balance mechanism inside that could withstand the problems that affected pendulum clocks. Local time was found using the position of the Sun, which was then compared against the time on the chronometer that had been set at a selected reference point, such as the start of the ship's journey. With this system mariners could find out the time difference and therefore accurately gauge where they were in the world.



FATHERS OF TIME

MEET THE PEOPLE WHO DEVISED THE TIMEKEEPING DEVICES WE NOW TAKE FOR GRANTED

Peter Henlein
1480-1542
Henlein designed the first watch. His portable brass devices became so popular he was asked to design a clock face for a German castle.

Christiaan Huygens
1629-1695
The Dutch scientist patented the first pendulum clock in 1656, based on the theory of pendulum motion that was first discovered by Galileo.

Eli Terry
1772-1852
Terry set up a clock making business in his home state of Connecticut, US. His firm helped mass-produce wooden shelf clocks for US citizens.

Louis Essen
1908-1997
Essen was a talented physicist who helped create some of the world's first atomic clocks and develop the idea of a standard second.

Lamarr had an 'inventing room' in her home and shelves full of engineering books

Lamarr used her profile to help the war effort through fundraising

A LIFE'S WORK

LAMARR'S BEAUTY AND BRAINS COMBINED TO CHANGE THE WORLD

1914
Hedwig Kiesler is born in Vienna, Austria-Hungary, on 9 November.

1937
Kiesler signs a contract with MGM Studios, moves to Hollywood and changes her name to Hedy Lamarr.

1942
Lamarr and composer George Antheil are granted a patent for their Secret Communications System.

1957
Lamarr's technology is adapted for use in transmitting the positions of enemy submarines.

WI-FI TECH

BEHIND THE SCENES OF HEDY LAMARR'S TECHNOLOGICAL BREAKTHROUGH

On the big screen, Hollywood siren Hedy Lamarr captivated audiences with her stunning beauty and acting talent, but when the cameras weren't rolling she could be found developing a technology that would go on to change the world.

Born in 1914 in Vienna, Austria-Hungary, young Hedwig Kiesler (her original name) dropped out of school to pursue acting, first in Czechoslovakia and then Hollywood, where she changed her name to Hedy Lamarr. Despite not completing her education, she retained a passion for knowledge and loved to tinker with contraptions in her trailer. She came up with an idea for an improved traffic stoplight, a tablet that would dissolve in water to create a carbonated drink, and, while dating aviation tycoon Howard Hughes, she helped him develop a racing airplane to sell to the US Air Force.

However, by far her most successful creation was 'frequency hopping'. When World War II broke out, the Jewish-born Lamarr felt uncomfortable living in luxury in Hollywood while her people suffered horrific persecution in Europe, so she decided to use her brain to help the war effort.

She had picked up a great deal of knowledge about weapons technology while married to her first husband, munitions manufacturer Fritz Mandl, and along with her friend and composer George Antheil she came up with a revolutionary idea that would prevent the Allies' torpedoes from being intercepted by the enemy.

Although they were granted a patent for their 'Secret Communications System' in 1942, the US Navy turned them away. Lamarr then offered her weapons expertise to the National Inventors' Council but was told that she should use her looks to help the war effort instead.

Lamarr's brains were overshadowed by her beauty throughout her life. While she achieved worldwide fame as 'the most beautiful woman in the world' and as the star of such films as *Algiers* and *Samson and Delilah*, her contribution to science and technology went largely ignored.

In the 1950s the idea of frequency hopping was finally adopted by the military, but because her patent had expired Lamarr was uncompensated. Later, it became critical for the development of wireless communication, making the Bluetooth and Wi-Fi technology that many of us use every day possible, but still she received no credit.

It wasn't until the final few years of her life that Lamarr was honoured for her groundbreaking invention. After her death, she was also inducted into the National Inventors Hall of Fame. Today, Hedy Lamarr is rightly remembered not only as a glamorous star of the silver screen, but also for her brilliant and revolutionary idea which now connects all of the small screens in our pockets.

Lamarr became a spokeswoman for war bonds during WWII

FREQUENCY HOPPING

During World War II, the Allies' radio-controlled underwater missiles could be easily detected by German submarines because the signals were broadcast over a single frequency. To solve this problem, Lamarr and piano composer George Antheil developed a system called 'frequency hopping', which could rapidly switch the signal to one of 88 different frequencies – the same number of keys on a piano – seemingly at random. Only those who knew the chosen combination of frequencies could intercept the signal, while everyone else just heard noise. This later formed the basis of the spread spectrum technology used to prevent interference in Bluetooth, Wi-Fi and GPS communication.

The Secret Communications System was intended to protect the Allies' torpedoes

5 THINGS TO KNOW ABOUT... HEDY LAMARR

1 SHE WAS A PLASTIC SURGERY PIONEER
In later life, Lamarr gave her surgeons new ideas for cutting and folding her skin to better hide the scars. Her techniques became widely used in the industry.

2 SHE RAISED MILLIONS FOR THE TROOPS
After being turned away by the National Inventors Council, Lamarr helped the war effort by becoming a spokeswoman for war bonds and managed to raise $7 million in just one night.

3 SHE WAS TYPECAST
Lamarr's beauty eventually proved to be a curse. The actress began to grow bored of being cast in movies just for her good looks, saying: "Any girl can be glamorous, all she has to do is stand still and look stupid."

4 SHE HAS AN 'OSCAR FOR INVENTING'
In 1997, Lamarr became the first woman in history to receive the coveted Invention Convention's BULBIE Gnass Spirit of Achievement Award, known as the 'Oscars of inventing'.

5 SHE BECAME A RECLUSE
Towards the end of her life, Lamarr became intensely private, rarely venturing out of her home. Instead she spent up to seven hours a day talking to people on the phone.

1962
The US Navy begins to use Lamarr's invention on ships involved in the Cuban Missile Crisis.

1997
The Electronic Frontier Foundation gives Lamarr and Antheil the Pioneer Award for their work.

2000
Lamarr dies on 19 January of heart disease in Florida, US, aged 85.

2014
Lamarr and Antheil are posthumously inducted into the National Inventors Hall of Fame.

"LAMARR'S BRAINS WERE OVERSHADOWED BY HER BEAUTY THROUGHOUT HER LIFE"

THE ELECTRIC LIGHT BULB

SHEDDING SOME LIGHT ON ONE OF THE MOST WORLD-CHANGING INVENTIONS

Today the electric light bulb is an essential part of society, with virtually all streets, homes and vehicles installed with one. The invention has literally lit up the Earth and transformed how we live.

The beginning of the journey to the electric light bulb began in 1799 when Italian physicist Alessandro Volta invented the voltaic pile (battery). The details of the battery soon spread through Europe, with many scientists replicating it and experimenting with its power-giving capabilities. One of the most notable of these scientists was British physicist Sir Humphry Davy, who built one at the Royal Institution in 1802.

In 1810, after much experimentation, Davy invented the first arc lamp, a temporary electric light source enabled by connecting two carbon rods to the battery's terminals and bringing them to within a couple of millimetres of each other. This caused the electric current to jump between the two, creating a bright plasma stream that illuminated the immediate surrounding area. Unfortunately, the intensity of the plasma soon caused the carbon rods to burn away and the invention did not gain commercial traction. However, the use of carbon and a variety of other metals as electrodes and filaments did, leading a number of scientists to create crude lights. But none were sustainable.

The next major breakthrough came in the realisation that the electrodes/filaments used in incandescent lights could be protected from quick destruction by placing them within a vacuum filled with an inert gas (as demonstrated by Warren de la Rue in 1840). This, along with the later discovery that filaments could be carbonised, allowed the creation of basic light bulbsthat, rather than lasting seconds or minutes, would work for hours and eventually days. Indeed, throughout the mid 19th century numerous scientists showed such bulbs to their friends and at public demonstrations.

This series of prototypes culminated in 1879 when Joseph Swan successfully demonstrated and then sold a light that used a single coil of carbonised artificial cellulose fibre embedded within an airless glass bulb. This was the first commercially sold incandescent light bulb. Critically, though, its adoption was only on a very small scale as, despite the bulb proving resilient, the power source needed was largely unavailable, with no electric infrastructure in place to support a wide-scale rollout.

This set the scene for Thomas Edison, who in 1880 successfully patented his own light bulb, which aside from being an improved design to that of Swan, was backed up by Edison's own electric generator, a package that would enable him to largely corner the new market for electric lighting that was set to take off.

Thomas Edison standing in front of his electric generator, a key factor behind his light bulb's phenomenal success

A replica of Thomas Edison's original light bulb, which was patented in 1880

LIGHT BULB EVOLUTION

AFTER THOMAS EDISON BROUGHT LIGHT BULBS TO THE MASS MARKET, WHAT HAPPENED NEXT?

1903 Tantalum

After the carbon rod light bulb, scientists test new filament materials to improve brightness. In 1903, Siemens and Halske try using tantalum.

1906 Sinter-lating

The General Electric Company, which was co-founded by Thomas Edison, patents a method of making filaments from sintered tungsten.

1913 Inert

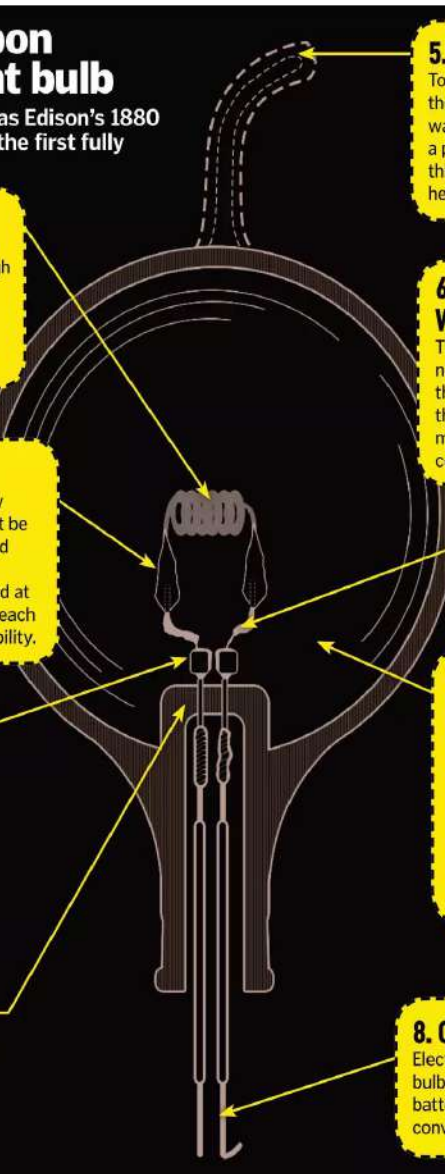
American physicist Irving Langmuir discovers that filling bulbs with inert gas rather than just a vacuum results in twice the luminous efficacy.

1917 Festive lighting

Electric Christmas lights see a boom in 1917 when Albert Sadacca is inspired to start making them after a fire in NYC caused by candles in a tree.

Inside a carbon filament light bulb

We take a look at Thomas Edison's 1880 electric lamp, arguably the first fully functioning light bulb



1. CARBON SPIRAL
Edison used a carbonised (achieved by heating it to high temperatures), high-resistance filament, which was coiled in the centre by winding it around a bobbin.

2. FILAMENT ENDS
As the filament coil was very thin and delicate, it could not be attached to the platinum lead wires directly. Instead lamp-black and tar were used at the ends as a mould around each connection, ensuring its stability.

3. CLAMPS
The platina wires were attached to the platinum lead wires with two mini clamps encased in the bulb.

4. LEADING WIRES
The light bulb's leading wires were made out of platinum due to its high melting point of 1,772°C (3,222°F) and low resistance compared to the filament.

5. VACUUM TUBE
To create a vacuum within the bulb, a vacuum tube was blown that attached to a pump. After exhaustion, this entrance was hermetically sealed.

6. PLATINA WIRES
The carbon filament was not directly attached to the platinum lead wires via the lamp-black and tar mould. Instead two platina contact wires were used.

7. VACUUM BULB
The bulb for the filament was roughly spherical and made from glass. The inside was a vacuum - something achieved by drawing out the oxygen through a top-mounted vacuum tube.

8. COPPER WIRES
Electric current for the light bulb was supplied from a battery/generator through conventional copper wires.

Top 5 facts: light bulbs

1 Evaporation
Under sustained use, the filament of modern-day tungsten bulbs will evaporate before condensing on the inner surface of the glass envelope and blackening it.

2 Halogen
Halogen lamps reduce evaporation of their filament and the darkening of the surrounding glass by filling the lamp with halogen gas at a very low pressure.

3 Inefficient
Despite modern bulbs lasting for long periods of time, about 90 per cent of the power they consume is emitted as heat, rather than light.

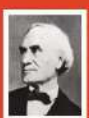
4 Bulb boom
In 1885 there were estimated to be about 300,000 incandescent lights in use, a number that then exploded over the subsequent decades up to 795 million by 1945.

5 Old-timer
The Livermore Centennial Light Bulb at a fire station in California, USA, has been burning non-stop since 1901. It is the record holder for longest operational bulb in the world.

BRIGHT SPARKS: THE RACE TO THE COMMERCIAL LIGHT BULB

SIR HUMPHRY DAVY
In 1802, British scientist Sir Humphry Davy used his large battery to pass a current through a thin strip of platinum. The experiment worked, but the platinum did not glow very brightly and wore out too quickly to be practically implemented into a lamp.

WARREN DE LA RUE
In 1840, chemist and astronomer Warren de la Rue enclosed a platinum coil in a vacuum tube and passed an electric current through it. This was one of the first true light bulbs as we know them today, but its cost and complexity made it impractical to roll out.



JEAN ROBERT-HOUDIN
This illusionist created his own incandescent light bulbs and showed them publicly at his estate in 1852. Again, they were curiosities and no practical production process or cost-efficient materials meant they couldn't be produced commercially.

ALEXANDER LODYGIN
In 1872, Russian Lodygin obtained a patent for an incandescent light bulb that used carbon rods in a nitrogen-filled, sealed bell glass receiver. He later moved to the US and applied for many patents, showing a molybdenum filament at the Paris World Fair in 1900.

JOSEPH SWAN
This British physicist arguably created one of the first sustainable light bulbs, demonstrating his carbon rod bulbs in 1878-79. He received a patent and began installing them in a few homes and theatres. He later partnered with Edison and set up the Ediswan Electric Company.

1937 Krypton-light
Production of light bulbs filled with the noble gas krypton begins in Hungary.

1977 Energy saving
Energy-saving light bulbs begin to be introduced to the market, leading to the generation of compact fluorescent lamps.

1991 Long-lasting
The electronics company Philips produces a fluorescent light bulb that lasts 60,000 hours through the process of magnetic induction.

2010 Green light
In many countries worldwide incandescent light bulbs begin to be phased out in favour of more eco-friendly LED and fluorescent types.

2012 Lights out
From 1 September, an EU directive bans all retailers from selling incandescent bulbs. It's hoped this will save an annual 39 terawatt hours by 2020.

WIRELESS ELECTRICITY

FIND OUT HOW NEW TECHNOLOGY IS SET TO MAKE POWER CABLES A THING OF THE PAST

Own an electric toothbrush? Then you already have wireless electricity at home. Toothbrush chargers use inductive coupling to provide power without electrical contacts. When current from the mains runs through a coil of wire in the charger unit, it produces a fluctuating magnetic field that induces a current in a second coil embedded inside the toothbrush. This principle also underlies charging mats that power up phones and cameras at close range.

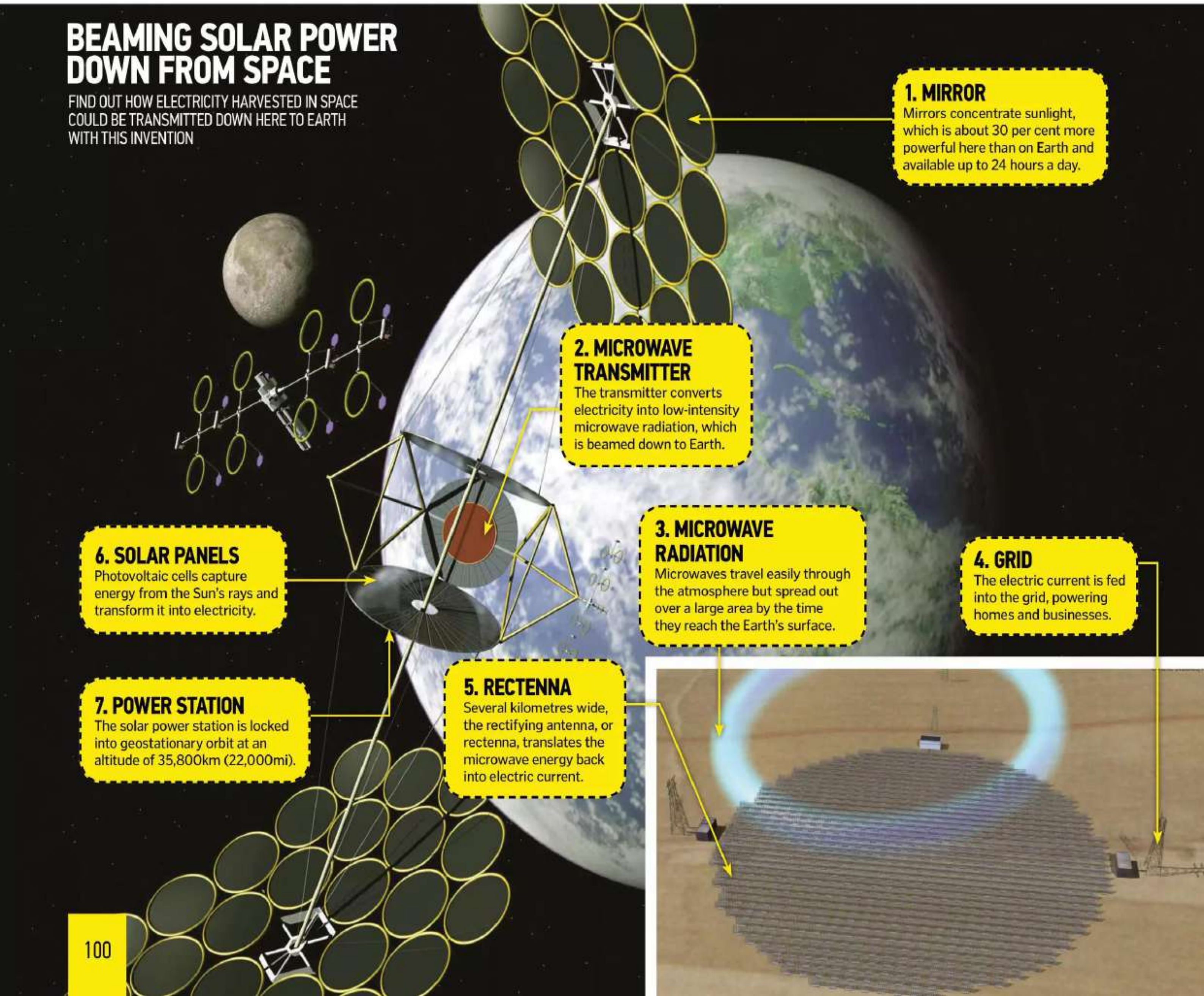
The catch, however, is that inductive coupling is only effective over a very short range – indeed, stray by just a few millimetres and the magnetic field tails off rapidly.

One solution is to throw resonance into the mix. Resonance is the phenomenon that enables an opera singer to shatter a wineglass with their voice alone. For this to happen, the frequency of the singer's voice has to match the glass's innate resonant frequency – the rate at which the glass naturally vibrates.

To apply this idea to wireless electricity, scientists fine-tune two coils to resonate to the same frequency of magnetic field. This makes transmission across a few metres possible as the second coil amplifies the energy of the first. The low-frequency magnetic fields used don't interact with people or pets, making this tech safe to use in a domestic environment.

If you want to beam power over much greater distances, though, converting energy into electromagnetic radiation (for example, light or microwaves) is the way to go. Laser-transmitted power has already been used to power unmanned aircraft. First, electricity is converted into a high-powered infrared laser beam; a photovoltaic cell at the other end then turns this back into electrical current.

Microwave-transmitted power follows much the same idea, converting energy into microwaves then back into current with the aid of a rectifying antenna, or rectenna. Although this is more efficient than laser beams it does require much bulkier equipment.



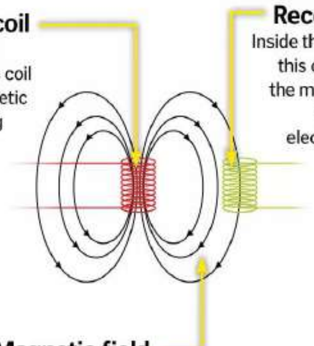
WIRELESS ELECTRICITY AT HOME

HOW WIRELESS ELECTRICITY COULD RID OUR HOMES OF THOSE PESKY POWER CABLES

A common example of wireless electricity in the home is the electric toothbrush, which uses inductive coupling technology

INDUCTIVE COUPLING

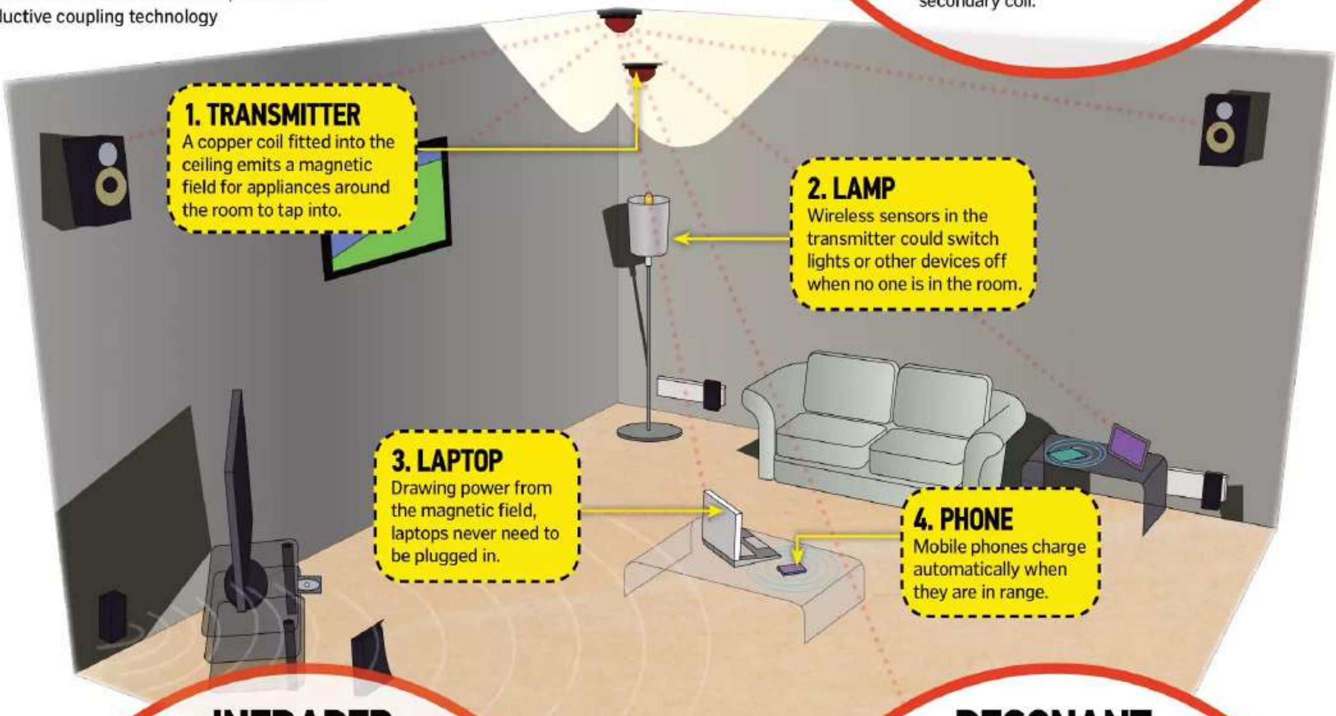
USED IN PHONES, CHARGING MATS, TOOTHBRUSHES



Transmitter coil
Connected to the power socket, this coil generates a magnetic field as alternating current travels through it.

Receiver coil
Inside the appliance, this coil converts the magnetic field back into an electric current.

Magnetic field
The field extends over a few millimetres to induce a voltage in the secondary coil.



1. TRANSMITTER
A copper coil fitted into the ceiling emits a magnetic field for appliances around the room to tap into.

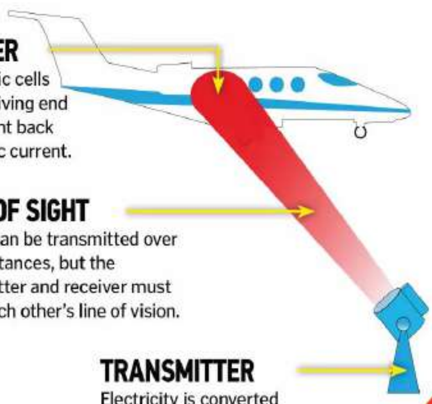
2. LAMP
Wireless sensors in the transmitter could switch lights or other devices off when no one is in the room.

3. LAPTOP
Drawing power from the magnetic field, laptops never need to be plugged in.

4. PHONE
Mobile phones charge automatically when they are in range.

INFRARED RADIATION

USED IN LAMPS, REMOTE CONTROLS, EPHOTO FRAMES



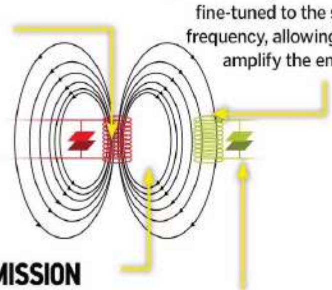
RECEIVER
Photovoltaic cells at the receiving end convert light back into electric current.

LINE OF SIGHT
Power can be transmitted over long distances, but the transmitter and receiver must be in each other's line of vision.

TRANSMITTER
Electricity is converted into a concentrated beam of infrared.

RESONANT INDUCTION

USED IN TELEVISIONS, LAPTOPS



RECEIVER
The receiving resonator is fine-tuned to the same frequency, allowing it to amplify the energy.

TRANSMITTER
Energy oscillates between an electric field in the capacitor and a magnetic field in the coil.

TRANSMISSION
This allows for power to be transmitted safely over 2-3m (6-9ft) and even through obstacles.

CURRENT
An electric current is induced in the receiving coil.

The MARS earbuds won the Best of Innovation award at 2018's CES

REAL-TIME TRANSLATORS

COULD NEW TECHNOLOGIES HELP US BREAK DOWN LANGUAGE BARRIERS?

Unveiled at CES 2018, the MARS wireless earbuds (developed in a joint effort by the NAVER Corporation and LINE Corporation) showcased the future of real-time language translation. Powered by Clova AI, the MARS wireless Bluetooth earbuds can translate speech from another language into the wearer's native tongue almost instantly.

Clova works as a voice-controlled virtual assistant – similar to Alexa or Siri – that listens to your conversation and transmits the data to your smartphone via Bluetooth. The accompanying app then translates the speech and transmits a recording of the translation back to the earbuds, which play it back for you to hear. All this happens within a fraction of a second, so the translations are relayed in almost real time. Each pair of earbuds can work as a single translator for two people. For use in crowded areas, MARS also features noise-blocking technology to focus on individual conversations. The current MARS can translate ten different languages, including English, Japanese and French, but 40 languages may be supported in the near future.

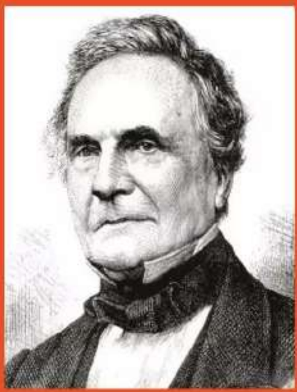
MARS isn't the only product breaking the language barrier. Waverly Labs have created The Pilot, which works in a similar fashion to the MARS. However, translations are consecutive, so you have to wait for a person to stop talking before the translation is then played back through the earbuds.

Google has put its eponymous Translate technology to use in their Google Pixel Buds. However, in this system only one person wears the earbuds. Their side of the conversation is translated and then played to the non-wearer via the app instead.

The Pilot earbuds have noise-blocking capabilities to minimise surrounding sounds

THE FIRST COMPUTER

CHARLES BABBAGE INVENTED THE FIRST COMPUTER, CALLED THE DIFFERENCE ENGINE. HOW ON EARTH DID IT WORK?



CHARLES BABBAGE

Born in London in 1791, Charles Babbage was a mathematician, philosopher, inventor and mechanical engineer. He was formerly tutored as a child in Devon and Middlesex, and in 1810 he attended Trinity College where he claimed to be disappointed in the mathematical education available. Teaming up with John Herschel and George Peacock, among others, Babbage and company formed the Analytical Society in 1812. In 1814 he married Georgiana Whitmore and moved to Dudmaston Hall in Shropshire where he engineered the central heating system. The couple had eight children, three of which survived to adulthood. In 1827, Charles' wife, father and at least one son died – it was these sad events that caused the inventor to suffer a mental breakdown, delaying the construction of many of his machines. He died aged 79, it is thought of "renal inadequacy, secondary to cystitis". Half of his brain is preserved in the Hunterian Museum in the Royal College of Surgeons, London.

The Difference Engine is the first automatic, mechanical calculator designed by British mathematician Charles Babbage, who proposed its construction in 1822 to the Royal Astronomical Society. He suggested the machine would employ the decimal number system and would be powered by turning a handle, as a method to calculate mathematical tables mechanically, therefore removing the high rate of human error.

At first Babbage received financial backing from the British Government, but this was later pulled when no apparent progress had been made on constructing the device. The inventor went on to design a more general analytical engine and then later in 1847 an improved engine design – the Difference Engine No. 2.

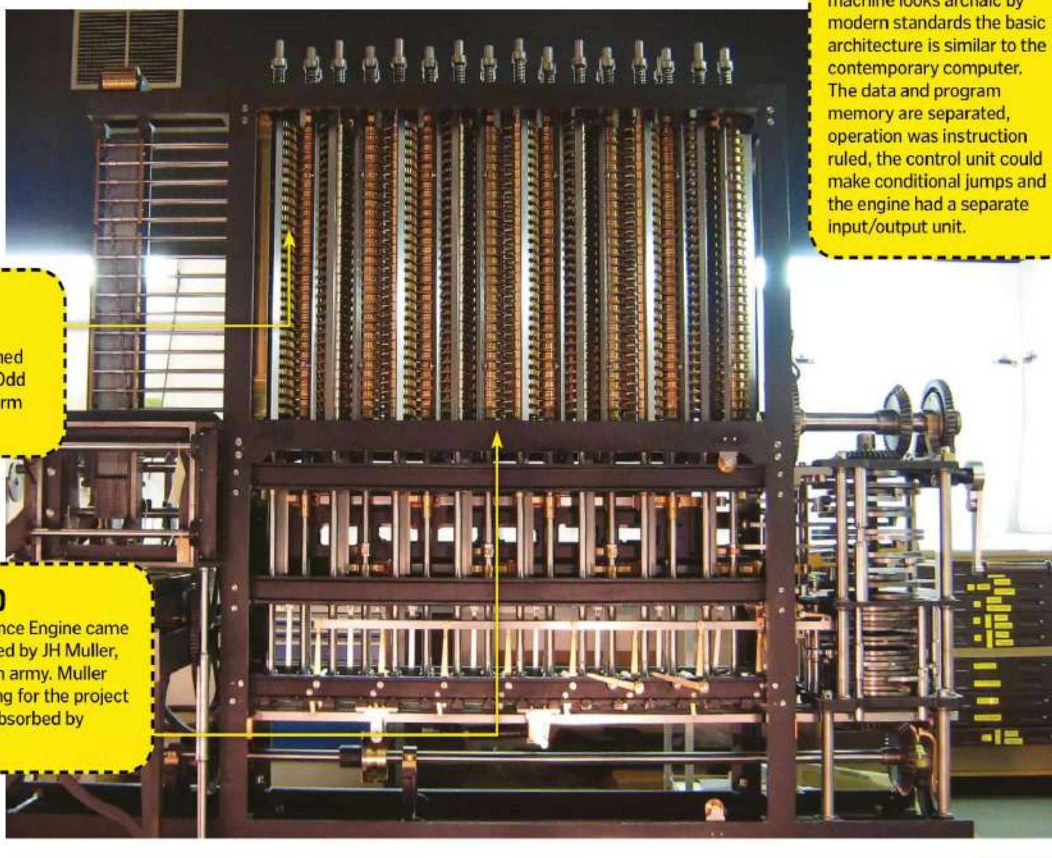
From 1989 to 1991, using the original plans of this second version, the London Science Museum constructed Babbage's envisaged machine. Faithful to the original designs, the machine consists of over 8,000 parts, weighs five tons and measures 11 feet in length. In 2000, the printer that he plotted to accompany the engine was added and together they performed as the inventor had intended over 100 years before. The machine's completion ended a long-standing debate as to whether Babbage's designs would've worked.

A NEW IDEA

Babbage designed the first mechanical computer – the Difference Engine – that eventually led to the invention of the first mechanical computer and as such is widely accepted as the 'father of the computer'.

KNOCK-ON EFFECT

Despite the fact the machine looks archaic by modern standards the basic architecture is similar to the contemporary computer. The data and program memory are separated, operation was instruction ruled, the control unit could make conditional jumps and the engine had a separate input/output unit.



MATHS IN ACTION

In Babbage's design, one full set of addition and carry operations happened once for four rotations of the crank. Odd and even columns alternatively perform an addition in one cycle.

BEING INFLUENCED

Inspiration for the Difference Engine came from a 1786 book published by JH Muller, an engineer in the Hessian army. Muller failed to secure the funding for the project and his ideas were later absorbed by Charles Babbage in 1822.

UNDERSTANDING PLASTIC

FROM TOOTHBRUSHES TO COMPUTER PARTS, MEET THE MATERIAL THAT HAS IT ALL

After ushering in a new era of affordable consumer goods in the 1950s, plastic has conquered the world. Plastics are incredibly versatile. They can be hard or soft, opaque or transparent, flexible, stretchy or brittle, and much more. But all plastics share one defining property: they can be moulded into almost any shape.

Synthetic plastics are manufactured by joining monomers – small carbon-containing molecules – into long chains called polymers. Most industrial plastics are made from monomers extracted from oil or gas. Combining different types of monomers into a variety of arrangements creates plastics with a wide range of properties. Inside a plastic, polymer chains entwine like a bowl of spaghetti, making plastic extremely durable. On the flipside, it takes centuries to break down.

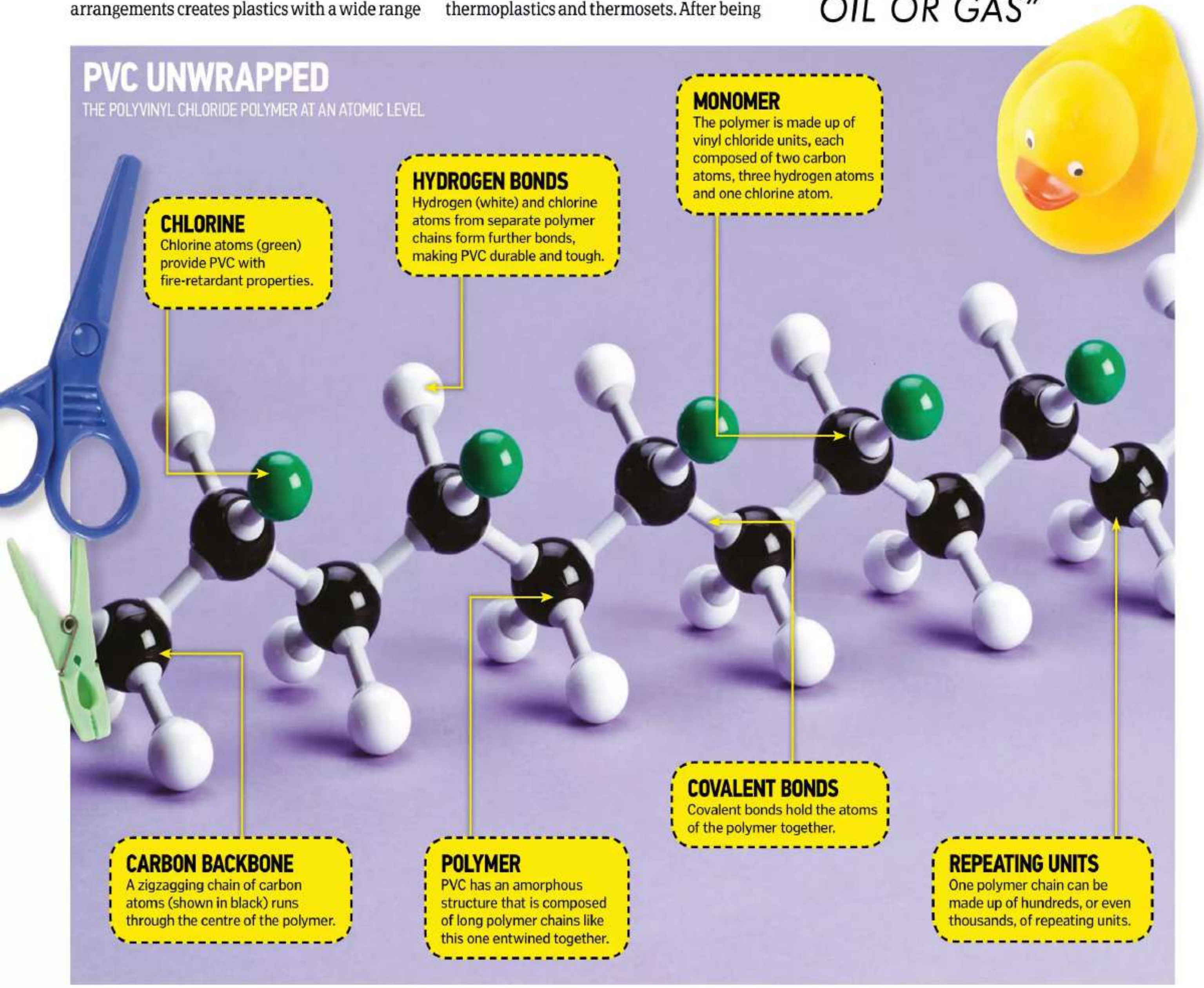
There are two main methods for joining monomers into polymers. In polymerisation, another chemical is added, acting as a catalyst and causing the monomers to combine to form a resin. Polycondensation involves combining monomers so that they release a by-product such as water or alcohol. With either process, additives such as pigments can be mixed in to modify its properties.

Plastics fall into two categories: thermoplastics and thermosets. After being moulded and cooled, thermoplastics can be melted and remoulded because their polymer chains bond weakly, and are easily broken by heating. Heat a thermoset, on the other hand, and its polymer chains bond in a way that cannot be undone – it is permanently 'set' into shape and can't be melted again.

> "MOST INDUSTRIAL PLASTICS ARE MADE FROM MONOMERS EXTRACTED FROM OIL OR GAS"

PVC UNWRAPPED

THE POLYVINYL CHLORIDE POLYMER AT AN ATOMIC LEVEL



KEY DATES
PLASTIC REVOLUTION

1870 Isaiah and John Wesley Hyatt patent celluloid, made from plant cellulose.

1907 Leo Baekeland mixes formaldehyde with phenol in order to create Bakelite.

1935 DuPont invents nylon, the first commercially successful thermoplastic.

1979 Global plastic production overtakes steel production – the end of an era.

2009 Coca-Cola launches its 'PlantBottle', a PET bottle containing up to 30 per cent bioplastic.

PRODUCING AND RECYCLING PLASTICS

To make a product, manufacturers melt plastic pellets and use one of several techniques to mould the plastic into its final shape. Plastic tubs, for example, are made by injection moulding, where heated pellets are injected into a mould cavity at high pressure. Films and piping, in contrast, are created by forcing the molten plastic through a small opening – a method that is known as extrusion.

Recycling plastics is, in theory, quite straightforward: grind the material down into flakes, wash away impurities, melt it back down into pellets and you're ready to start again. In practice it's a little more complicated. While thermoplastics such as PET can be melted down and reused, thermosets do not melt and cannot be recycled. Different types of plastic need to be sorted and processed separately, which is a labour-intensive process. Other plastics, such as polystyrene, are simply not cost-effective to recycle.

PLASTICS FOR ALL PURPOSES

Polyvinyl chloride (PVC)


PVC's durability and resistance to chemicals, grease and oil make it ideal for plumbing. It can be manufactured into rigid or flexible forms.

Polystyrene


Manufactured into a foam, polystyrene is an excellent heat insulator. Polystyrene chips or trays also absorb impacts to protect delicate goods.

Low-density polyethylene (LDPE)


Soft and flexible, LDPE is strong even when processed into thin sheets – so it's perfect for shopping bags. LDPE's molecular structure also gives it some stretch, making it suitable for food wraps.

Polyethylene terephthalate (PET)


A mainstay of the food and drink industry, PET is tough and impermeable to water and most gases. PET containers don't release chemicals into the food or fluid they contain.

Polypropylene (PP)

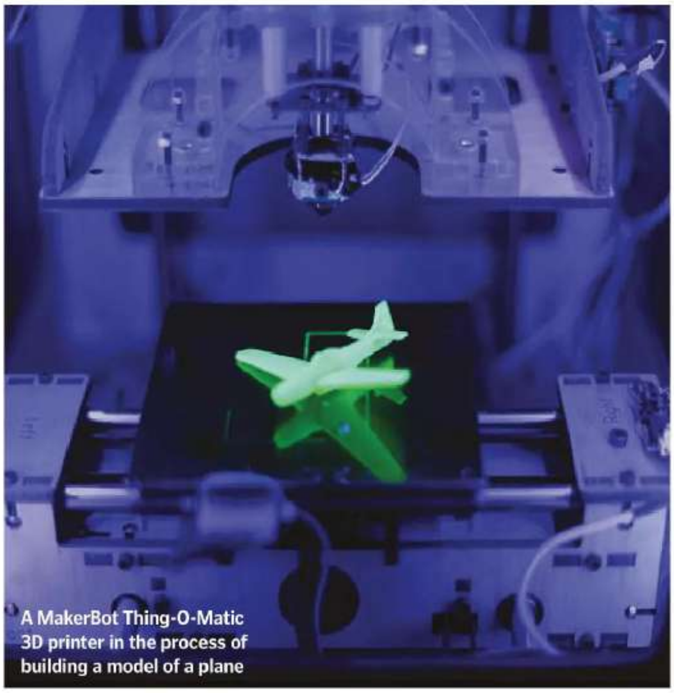

Polypropylene is strong yet flexible. Able to withstand higher temperatures than most plastics, it can be washed in the dishwasher or even heated in the microwave without warping.

IN THE FUTURE
PLASTICS AND POLYMERS UNDER DEVELOPMENT

With oil and gas reserves declining, the pressure is on to develop viable bioplastics, made from plants such as corn or cane sugar. More research is needed, however, to bring down their cost and resolve the environmental challenges they pose when it comes to biodegradability and recycling.

Self-healing polymers, meanwhile, could spell the end of scratches on your phone's screen. Different methods exist, one being to add microcapsules of a 'healing agent' to a polymer structure. When the plastic is damaged, the healing agent oozes out, catalysing a reaction which bonds it back together.

Elsewhere 3D printing is opening up many new possibilities for what you can do with plastics. Instead of ink, a 3D printer head is filled with a polymer (or sometimes a metal) that it melts and prints in layers to create all manner of three-dimensional objects, from coat hooks to human bones for transplant.



A MakerBot Thing-O-Matic 3D printer in the process of building a model of a plane

INKJET PRINTERS

HOW THESE DEVICES PRODUCE DOCUMENTS AND PHOTOS WITH MICROSCOPIC PRECISION

An inkjet printer is really just a collection of motors, rollers and drive belts that move the paper around. Almost all of the complicated technology is in the print heads. These can either be fixed within the printer, or incorporated in the replaceable ink cartridge. A single print head contains hundreds or even thousands of microscopic nozzles, each one about ten times thinner than a human hair.

These nozzles are far too thin to be made from ordinary piping. Instead, tiny channels are etched directly into the same material used to make the circuitry that fires the ink droplets. Thermal inkjet printers incorporate tiny resistive heater elements about 15 microns (thousandths of a millimetre) across. To fire the ink, the heater is switched on for a millionth of a second and the ink right next to it instantly boils. This results in a steam bubble that expands and creates a pressure wave, which then flicks a droplet of ink out of the nozzle. Inkjet printers made by Canon, Hewlett-Packard and Lexmark all use this thermal technology, but Epson and Brother printers create a pressure wave in the nozzle by applying an electric charge to special piezoelectric crystals.

Each droplet contains just a few trillionths of a litre of ink and the printer can fire out tens of thousands of droplets per second. Most printers have four different colour inks: black, cyan, magenta and yellow, and some models also have cartridges for light cyan, light magenta, light yellow and light grey. These colours are layered on top of each other to create every possible shade. A single colour dot on the page might contain 32 separate ink droplets, and high-quality printers can produce millions of dots in every square centimetre.

Heavy-duty commercial inkjet printers can produce 75,000 pages from a single cartridge.

INK-CREDIBLE PRICES

Printer manufacturers have been accused of driving up the cost of ink cartridges in recent years by surreptitiously reducing the amount of ink in each one. A typical combined colour/black cartridge contains just 16 millilitres of ink, compared with 42 millilitres in 2003, and costs the same £20-£25. That works out at around £1,250-£1,500 per litre, which is roughly as expensive as Chanel No. 5 perfume. However, advances in printer technology mean that they waste less ink and you can still expect around 250 pages from a single cartridge. The cost of the printers themselves has also fallen, because manufacturers sell them almost at cost price and make all their profit from the ink cartridges.

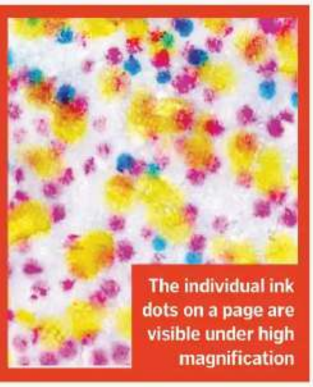
FROM PRINTER TO PAGE

EACH COMPONENT EXECUTES A PRECISELY CHOREOGRAPHED DANCE TO GET THE INK TO THE RIGHT SPOT

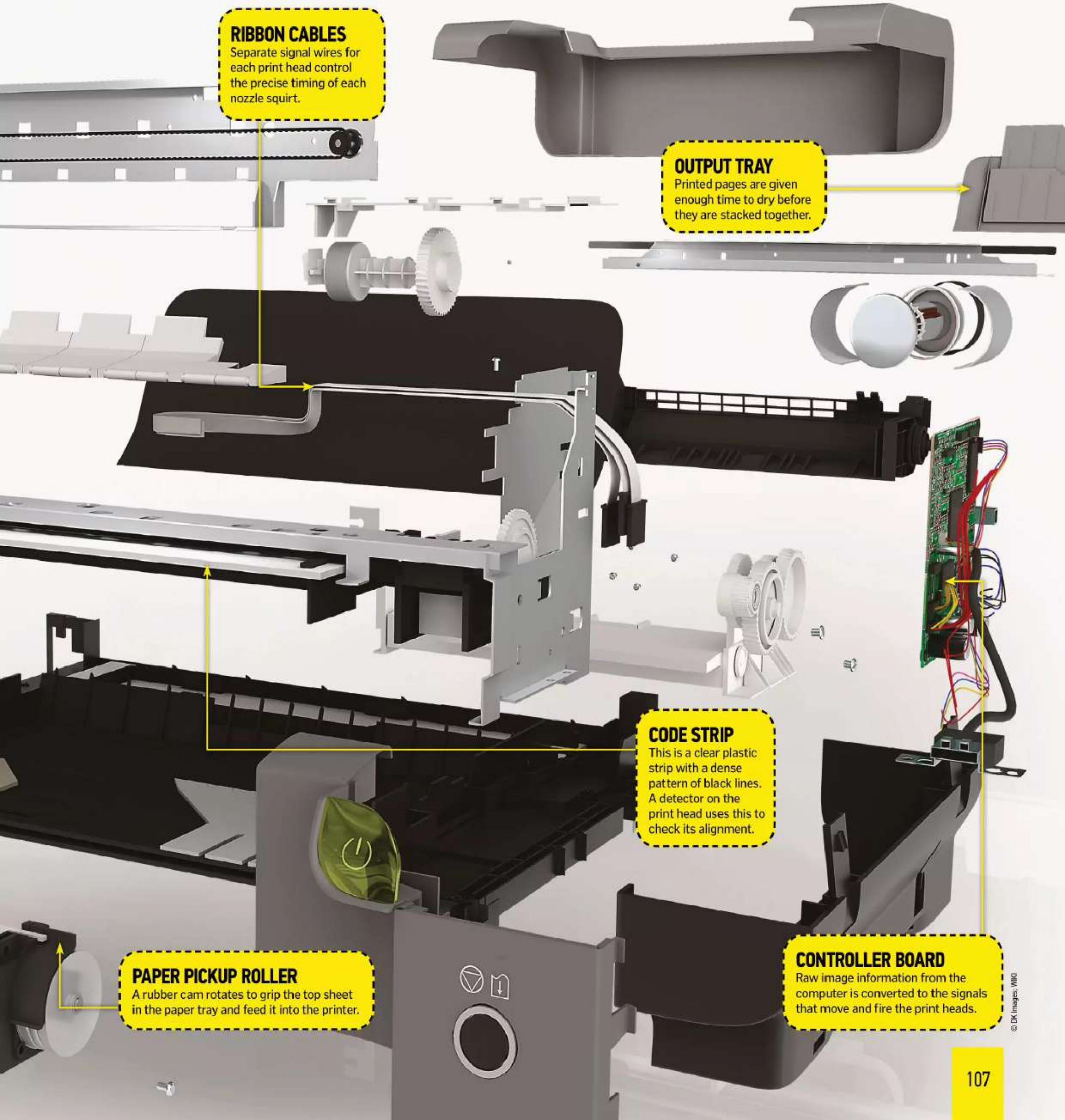
"A SINGLE PRINT HEAD CONTAINS HUNDREDS OF MICROSCOPIC NOZZLES, EACH ONE ABOUT TEN TIMES THINNER THAN A HUMAN HAIR"

CLOG-FREE COLOURS

Printer ink needs to dry quickly once it hits the paper, but if the ink dries in the nozzles then they will clog. When the printer isn't in use, the print heads are sealed with a rubber cap to keep them from drying out but during printing, individual nozzles might be uncovered for a long time, even though that particular colour isn't needed. To help keep them flowing freely, the print head deliberately scans past the edge of the paper and fires the unused nozzles into a small chamber, like the printing equivalent of a Wild West spittoon. It wastes a little ink, but much less than running a full cleaning cycle. Some printers will pause to wipe the print head against a rubber squeegee to clean off any crusted ink. This is often what is happening if the printer makes those strange clanking and whirring sounds when idle.

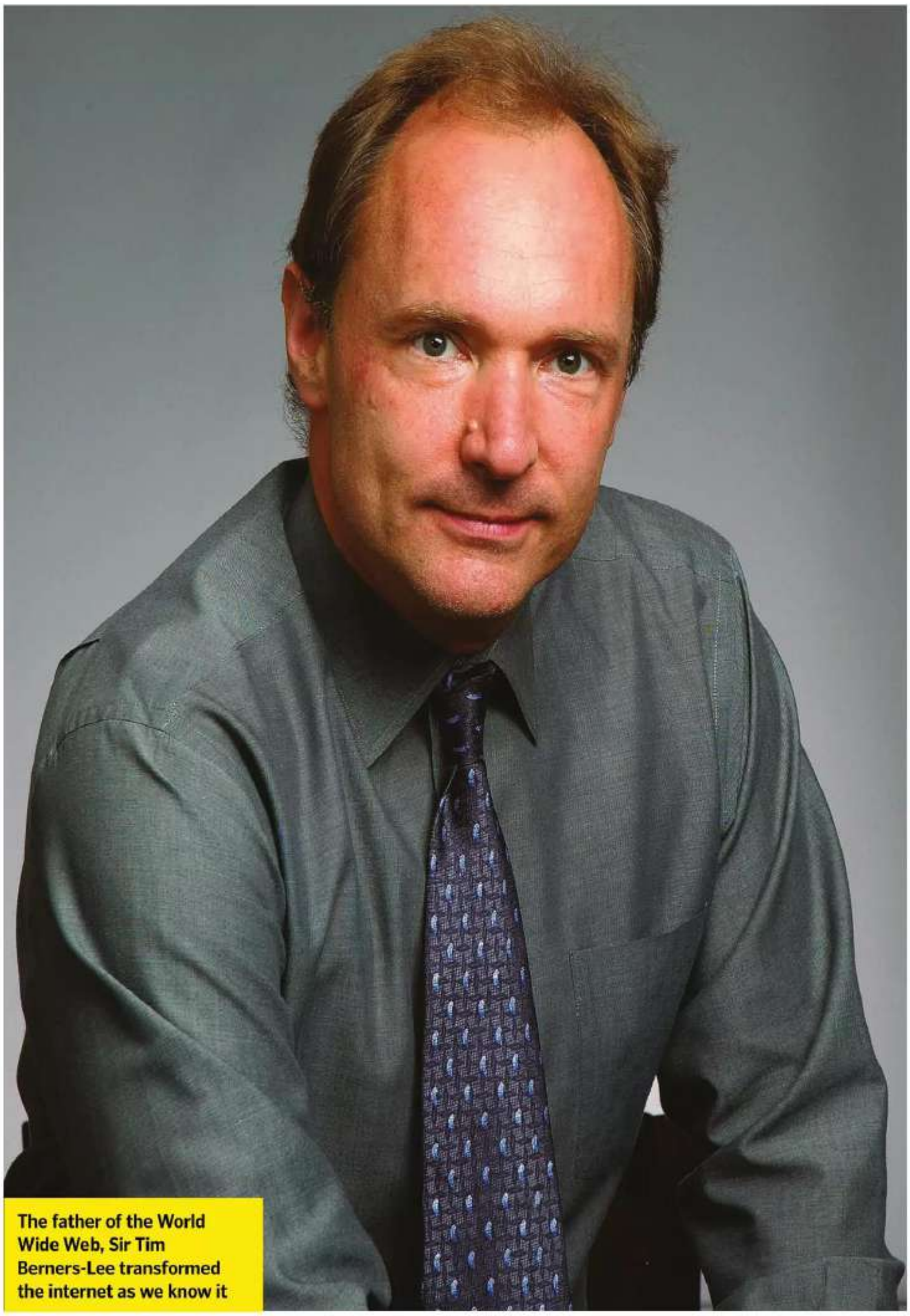


The individual ink dots on a page are visible under high magnification



THE WORLD WIDE WEB

MEET SIR TIM BERNERS-LEE, THE REVOLUTIONARY COMPUTER SCIENTIST WHO INVENTED THE WORLD WIDE WEB



The father of the World Wide Web, Sir Tim Berners-Lee transformed the internet as we know it

Born in June 1955 in London, Sir Timothy Berners-Lee's pioneering work has transformed every aspect of our lives; he is the creator of one of the greatest inventions of the 20th century. Berners-Lee was not the first in his family to master mathematics; his parents Conway Berners-Lee and Mary Lee Woods also dedicated their lives to the subject. His passion for science led him to attend Oxford University, where in 1976 he graduated with a first-class degree in physics.

After completing his degree, Berners-Lee moved on to become a scientist at CERN, the European Organization for Nuclear Research, in 1989. That same year, Berners-Lee published a paper titled *Information Management: A Proposal*, in which he suggested the combination of hypertext and the internet for an information management system.

In this initial proposal for the World Wide Web, Berners-Lee described the shortcomings of the then-current system at CERN in allowing scientists access to their information and documentation. Though the internet had been around for a decade, the information had limited accessibility. Berners-Lee set out to connect both the internet and a web-structured platform to revolutionise data sharing. To achieve this he created the Hypertext Transfer Protocol (HTTP), Uniform Resource Identifier (URI) and Hypertext Markup Language (HTML), the building blocks for internet browsing that remain in use today.

Created to better serve CERN scientists and assist those across the globe with their research, Berners-Lee launched the first website, http://info.cern.ch, in 1990. This new way to obtain information was something he wanted the entire world to have access to. He decided to make the World Wide Web an open and royalty-free software, allowing it to grow beyond academia. By 1994 there were around 3,000 websites in existence: today there are over 1 billion. After such a roaring success, Berners-Lee created W3C (World Wide Web Consortium), a web standards organisation that also develops web specifications, guidelines, software and tools. With the continued success of the iconic 'www.', Berners-Lee founded the World Wide Web Foundation in 2009, an organisation working to deliver digital equality to the world.

A LIFE'S WORK

THE ROAD TO AN INVENTION THAT TRULY CHANGED THE WORLD

1955
Berners-Lee is born on 8 June in London to parents Conway Berners-Lee and Mary Lee Woods.

1976
He graduates from the University of Oxford, earning a first-class degree in physics.

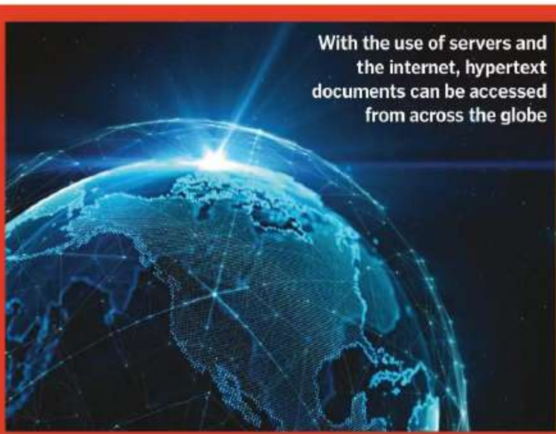
1989
While working at CERN, Berners-Lee invents the World Wide Web.

1990
The first web client and server is written by Berners-Lee.

1994
He becomes the director of the World Wide Web Consortium, developing interoperable technologies.

WEAVING THE WORLD WIDE WEB

The concept of the World Wide Web is relatively simple: it works to provide the user with information from a variety of sources in a non-linear fashion, hence a 'web'. The construction, however, is not so simple. Sir Tim Berners-Lee used something called hypertext to achieve this. By allowing text to hold more text and other information within it, users can jump from one place to another. It works in a similar way to how a hyperlink would work on a text document but in a continuous fashion. Combined with the global capacity of the internet, hypertext is placed within browser platforms and held on different servers to enable global connectivity.



With the use of servers and the internet, hypertext documents can be accessed from across the globe

Berners-Lee has been honoured with multiple awards over the years, including the prestigious ACM AM Turing Award (referred to as the 'Nobel Prize of computing'). In 1997, he was appointed an Officer of the Order of the British Empire (OBE), then in 2004 he was promoted to Knight Commander (KBE) "for services to the global development of the internet".

Following decades of scientific and economic success, Berners-Lee has now returned to his Oxford University roots. Joining the staff as a Professor of Computer Science, Berners-Lee is inspiring the next generation of digital creators.

Scientist Robert Cailliau (left) worked with Sir Tim Berners-Lee (right) on the World Wide Web project using the NeXT Cube computer

The NeXT Cube was the computer used to create the World Wide Web and was exhibited at the London Science Museum

"THIS NEW WAY TO OBTAIN INFORMATION WAS SOMETHING BERNERS-LEE WANTED THE ENTIRE WORLD TO HAVE ACCESS TO"

5 THINGS TO KNOW ABOUT… SIR TIM BERNERS-LEE

1
He has more than one doctorate
Berners-Lee has been bestowed with honorary degrees and doctorates from institutions around the world, such as the prestigious universities of Harvard and Yale.

2
He's in the hall of fame
He's in the Internet Hall of Fame, to be exact, launched by the Internet Society in 2012 to celebrate the living history of the internet and its many extraordinary contributors.

3
He was in the Olympics
You may have spotted Sir Tim in the opening ceremony of the 2012 Olympic Games in London, sat with the computer he originally used when developing the Web.

4
His parents were pioneers too
As mathematicians, his parents Conway Berners-Lee and Mary Lee Woods worked on the world's first commercially built computer, the Ferranti Mark 1.

5
The Web wasn't his first creation
In 1980 Berners-Lee designed a computer system called ENQUIRE to find and share information.

1999
Publishes his book *Weaving the Web*, which describes the development of the World Wide Web and his role in it.

2004
Knighted by Queen Elizabeth II for services to the global development of the internet.

2009
Berners-Lee is elected the foreign associate of the National Academy of Science.

2013
Awarded the Queen Elizabeth Prize for Engineering for "groundbreaking innovation in engineering that has been of global benefit to humanity".

2016
Berners-Lee wins the ACM AM Turing Award for the invention of the World Wide Web.

LARGE HADRON COLLIDER 2.0

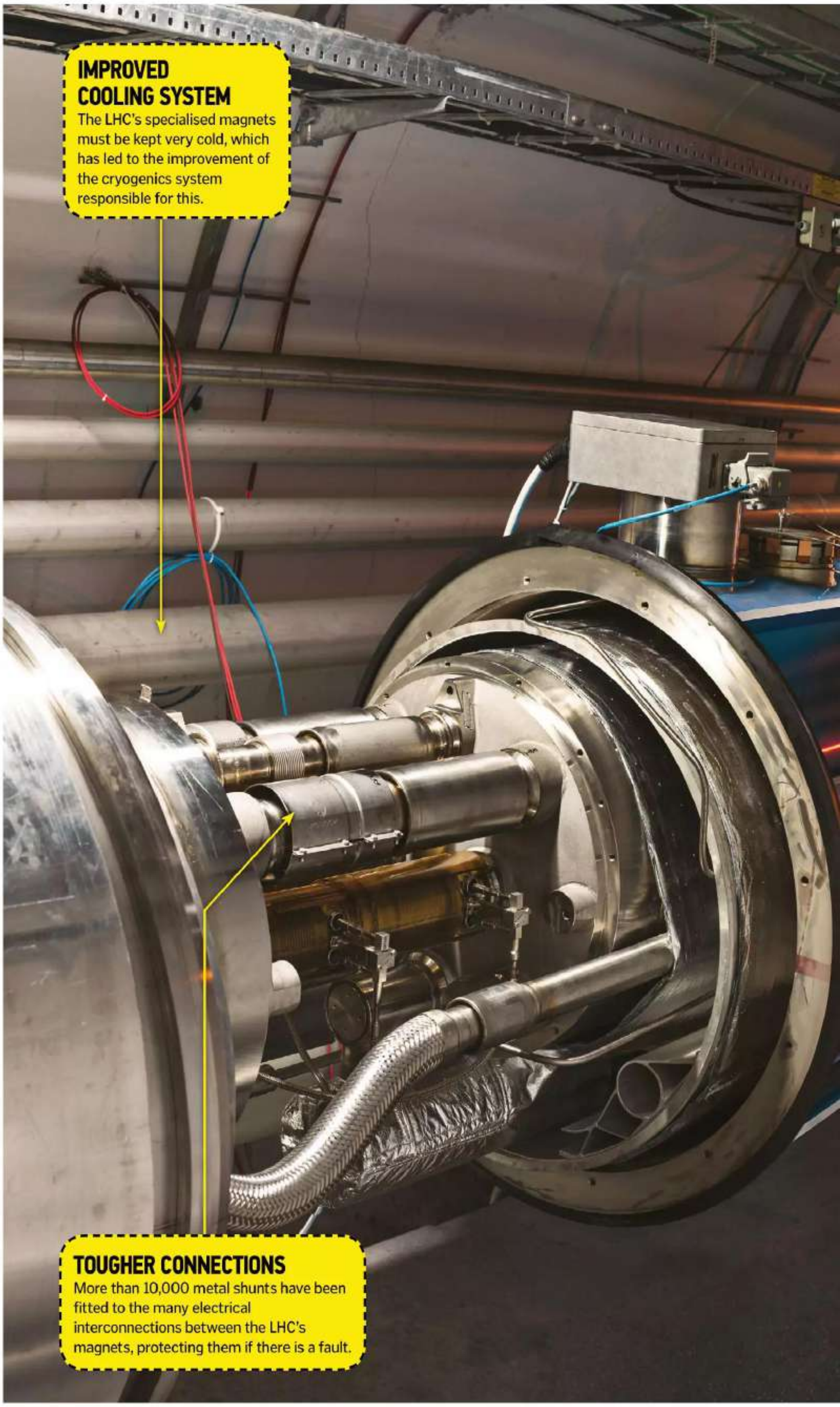
THE UPGRADES AND DISCOVERIES OF THE MOST POWERFUL PARTICLE SMASHER ON THE PLANET

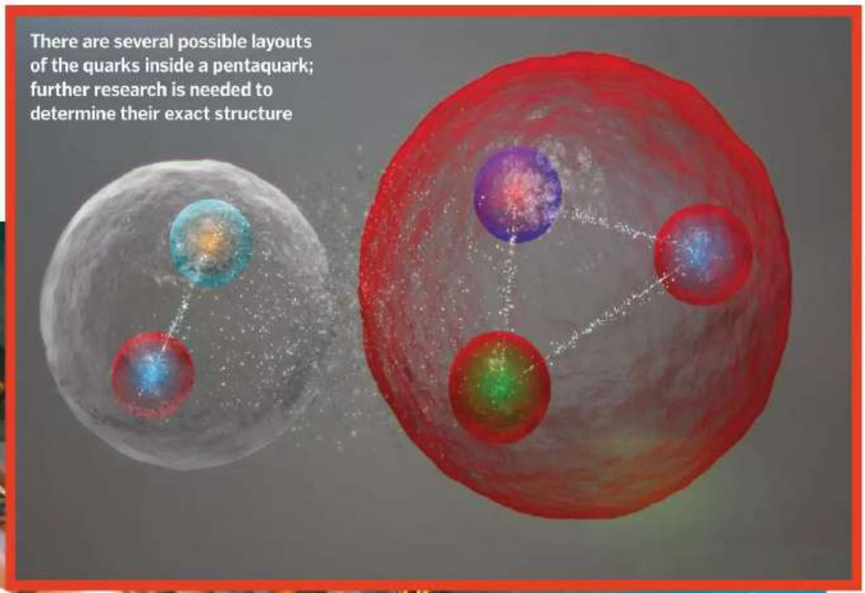
The world's most powerful particle accelerator is back, and it's better than ever. After being shut for two years of planned repairs and maintenance, the Large Hadron Collider (LHC) is smashing particles together at a record-breaking 13 tera-electronvolts, almost double the energy it was using in 2013.

Researchers at CERN hope this vastly improved energy output will allow more intricate studies of the Higgs boson – a particle that could explain why matter has mass – which was famously discovered in 2012. The increased energy should mean that Higgs boson particles are generated more frequently (it should be able to generate ten times as many as during the LHC's first run), helping researchers measure them more accurately and probe their rare decays. Furthermore, researchers hope that a more powerful LHC will be able to safely conduct more extreme experiments, which scientists believe will better simulate the conditions of the early universe.

In July 2015, the LHC's latest discovery was made: the pentaquark. This not only represented a brand new particle, but it also gave the researchers a way to group together quarks – the constituent particles of protons and neutrons – in a brand new pattern. This in turn could help us to understand how these subatomic particles are formed. Physicists have also set their sights on finding dark matter, which is known to make up around 85 per cent of all matter in the universe but whose nature is unknown. The only reason we know it exists is due to its gravitational effects, holding the universe together. Scientists have theories about the characteristics of the particles required for dark matter, but it may be that they uncover something else entirely. In January 2019, CERN presented designs for the Future Circular Collider, a potential successor to the LHC that would be around four times larger at 100km long. We will be watching this to see how it develops.

"THIS VASTLY IMPROVED ENERGY OUTPUT WILL ALLOW MORE INTRICATE STUDIES OF THE HIGGS BOSON"





There are several possible layouts of the quarks inside a pentaquark; further research is needed to determine their exact structure

HIGHER ENERGY BEAMS

One of the most significant improvements is the energy of collisions, which will now be 13 tera-electronvolts compared to eight tera-electronvolts in 2012.

SECURE VACUUM

To prevent electron clouds from interfering with the beam, the beam pipe has been coated with a special non-evaporable substance to take up electrons.

THINNER BEAMS

As beam widths decrease with increasing energy, the LHC's beams will now be more tightly focused to allow more collisions and interactions during experiments.

HOW WELLS WORK

GROUNDWATER IS AN IMPORTANT SOURCE OF FRESH WATER FOR PEOPLE ALL OVER THE WORLD

Our planet has an abundance of water, and it is the source of all life on Earth, but when you pour yourself a refreshing drink of cold water from the tap, you probably don't think of the kilometres it has travelled from its source to your glass.

More than 70 per cent of our planet is covered in water, and a large portion of fresh water is stored beneath the surface as groundwater. This groundwater can be accessed by building wells – something humans first invented around 8,000 years ago in the Neolithic period. These were mostly hand-dug wells, a method still relied upon by millions of people living in rural areas of developing countries today. However, many hand-dug wells are now having pumps added to their systems or are being built deeper as a result of more sophisticated methods that make extracting the water a much more efficient process than it once was.

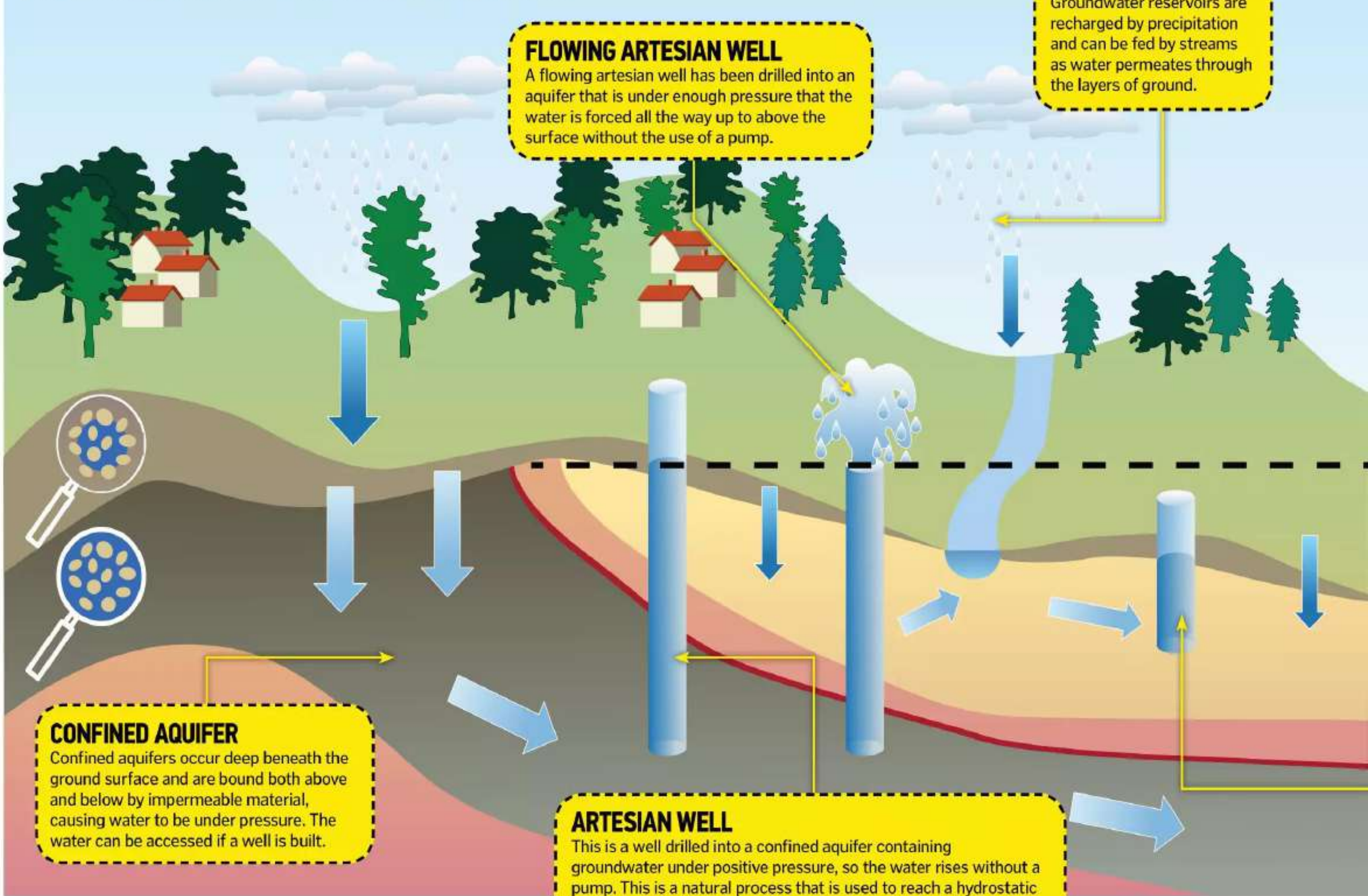
Wells accessing groundwater reservoirs provide 25 to 40 per cent of the world's drinking water. The reservoirs of water are stored under the surface in aquifers. Some aquifers are closer to the surface and are regularly replenished directly by rain (or melted snow) seeping into the ground, while others deeper in the ground may take longer to replenish as they gain their source from aquifers higher up.

Many of these reservoirs were recharged in ancient times over thousands of years, making them renewable sources of water. Wells are built into these aquifers using different methods to access the drinkable water below.

Wells are particularly vital for those who live in remote villages without modern water supply systems

WELLS, AQUIFERS AND GROUNDWATER

WHAT UNDERGROUND WATER SOURCES EXIST AND HOW DO WE ACCESS THEM?



RECHARGING
Groundwater reservoirs are recharged by precipitation and can be fed by streams as water permeates through the layers of ground.

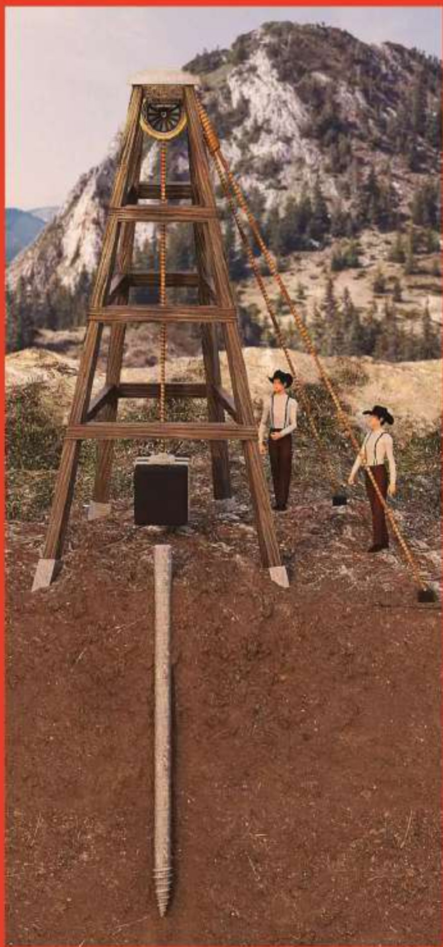
FLOWING ARTESIAN WELL
A flowing artesian well has been drilled into an aquifer that is under enough pressure that the water is forced all the way up to above the surface without the use of a pump.

CONFINED AQUIFER
Confined aquifers occur deep beneath the ground surface and are bound both above and below by impermeable material, causing water to be under pressure. The water can be accessed if a well is built.

ARTESIAN WELL
This is a well drilled into a confined aquifer containing groundwater under positive pressure, so the water rises without a pump. This is a natural process that is used to reach a hydrostatic equilibrium, but the water does not necessarily reach the surface.

BUILDING WELLS

THERE ARE THREE MAIN WAYS TO DIG FOR WATER...



DUG

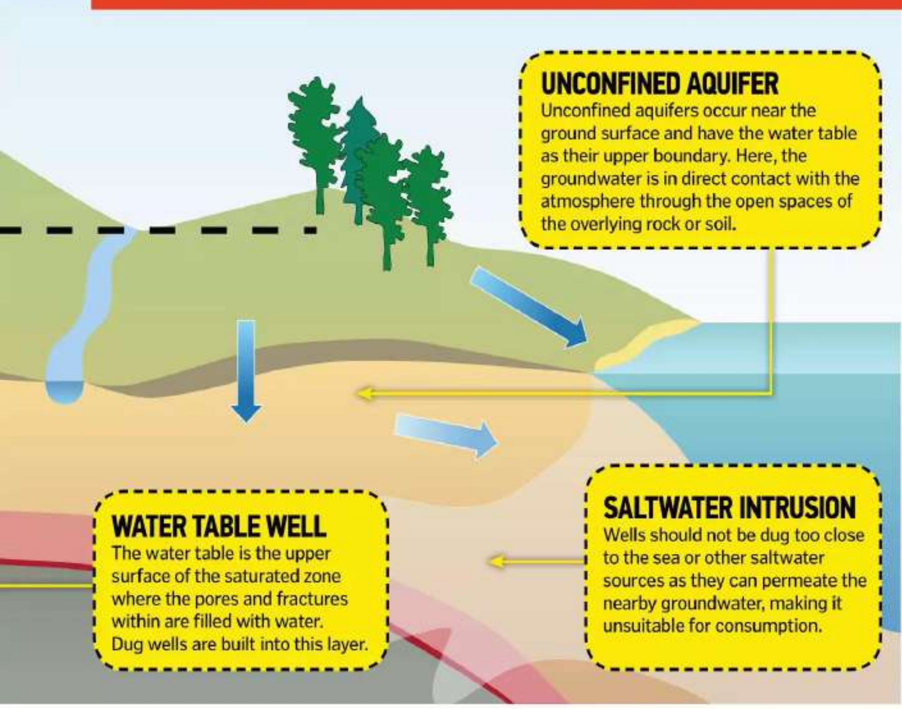
Dug wells are constructed below the groundwater table using a shovel. They are generally deepened until the digger finds water is filling the hole faster than they can bail it out. It is then lined with hard material to support it.

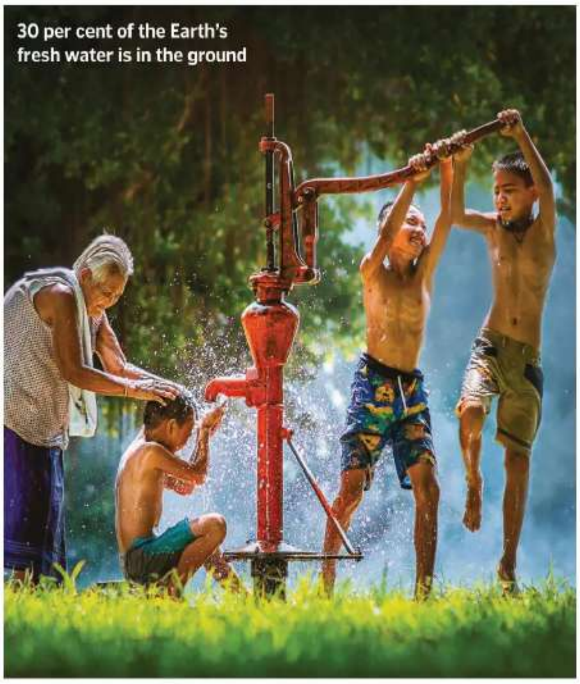
DRIVEN

A driven well is smaller in diameter and built by assembling thin lengths of steel pipe. Each section – a couple of metres long – is screwed together and driven into the ground up to a depth of around nine metres.

DRILLED

A drilled well is a hole bored into the ground. A lined casing is installed around the upper part of the well to prevent collapse and to stop surface or subsurface contaminants from entering the water supply.





30 per cent of the Earth's fresh water is in the ground

10 AMAZING WAYS DRONES ARE BEING USED

SEE HOW THE INVENTION OF DRONES HAS CHANGED THE WORLD

© microdrones

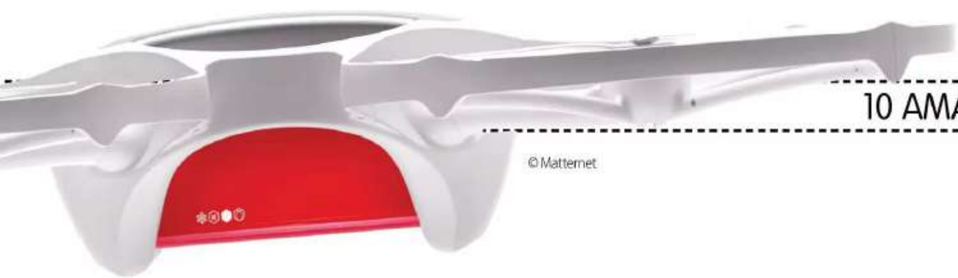
1. AIDING FARMERS

A drone is a cheap and effective way to survey large areas of farmland. With a multi-band sensor on a drone, farmers can capture images of crop using non-visible light. This enables them to produce information about the growth of the crop, and deploy fertiliser precisely where it's required. These sensors also reveal crop health, so pesticides can be applied strategically rather than universally.

2. FORECASTING THE WEATHER

Hurricanes and storms often cause loss of life and damage property, but with advanced warning, the damage can be reduced and lives saved. UAVs, such as AeroVironment's Global Observer, can keep an eye on developing weather conditions in real-time, and supply remote imagery and storm data to assist with life-saving measures. If terrestrial communications equipment, such as cell towers, microwave relays and satellite downlinks, are damaged, the Global Observer's communications payload can keep the emergency services connected, so that they can continue planning evacuations and relief operations, and coordinate their first response. The Unmanned Global Observer can fly for up to six days at a height of 55,000 feet, and cover an area 600 miles in diameter.

© Courtesy AeroVironment, Inc.



© Matternet

3. MONITORING COUNTRY BORDERS

Country borders can be vast areas to patrol using conventional technology, so drones are playing an increasingly large part in this role. The US government now uses fixed-wing Predator class UAVs to scrutinise the Mexican border for illegal traffic. Video is recorded in multiple passes, then the footage is mixed together to spot changes that could indicate the presence of drug smugglers, for example. Agents can then be directed to the appropriate areas.

© Gerald Nino, CBP, U.S. Dept. of Homeland Security

"A FARMER CAN CAPTURE IMAGES OF HIS CROP USING NON-VISIBLE LIGHT "

4. BRINGING AID

One of the challenges of transporting medical aid in developing countries is the lack of roads. Swoop Aero was chosen to deliver vaccines to parts of the Republic of Vanuatu using drones. Vanuatu is an archipelago in the South Pacific Ocean made up of over 80 islands – and not all have roads or an airfield. Parts of the drones used are made from 3D-printed materials so they are quick to produce if more are needed. They can fly up to 100 kilometres and carry around 2.5 kilograns worth of supplies. There are risks – drones can get lost in remote parts and storms can interfere. UNICEF has been in the country acclimating the locals to having unmanned vehicles flying in their villages.

5. INSPECTING OIL RIGS

UAVs are the perfect tool to make inspections at oil platforms much safer. Cyberhawk is an aerial inspection company that deploys its drones to perform visual inspections of high-value and high-risk offshore assets. By safely inspecting an active platform's flare (and the supporting structures) from a drone's live video feed, they can keep the platform online, saving the client time and money. The client can then pre-order and manufacture parts to upgrade the structure and keep it running smoothly. All of Cyberhawk's UAV pilots need to have offshore survival and medical certifications before they can operate a drone in an offshore platform environment.

©Cyberhawk

6. SURVEYING ARCHAEOLOGICAL SITES

As many archaeological sites are in remote locations, drones are a cheap and effective way to reach and survey these locations. Drones enable scientists to get a bird's-eye view that reveals new information about a site. An md4-200 microdrone UAV was used in Tuketa, in Russia's Altai Mountains, to survey ancient burial mounds (called Kurgans). This resulted in a 3D map of the site that could be used by scientists to measure the volume of the burial mounds. Professor Ian Lindsay from Purdue University used a DJI Phantom 2 to capture aerial data of burial mounds in Armenia.

© Project ArAGATS

7. DELIVERING PACKAGES

As the drone started to become a mainstream product, it didn't take long for forward-thinking companies to start looking at how they could begin integrating them into their businesses. One of the most obvious angles was as a means of delivering small parcels and packages. The potential in this area is huge, and the prospect of reducing the carbon footprint or delays due to traffic – or even the man hours sending people around the country to deliver items by hand – has got some of the big players looking at rolling a drone delivery service out sooner rather than later. Amazon is currently working on Prime Air to deliver small packages in under 30 minutes, and UPS has started testing their delivery drones that deploy from the top of their van.

8. MEASURING AIR QUALITY

Instead of payloads, such as video cameras, drones can be made to carry a range of sensors to take meteorological measurements, such as temperature, humidity,air pressure and more. They could also carry and use sensors that will detect poisonous particles in the air, as Fire Chief Andy Cashmore explains: "They could look for fibres and heavy metals in the smoke, and that will include asbestos." In China, a drone is being tested as part of the war on pollution. A parafoil helps the drone stay aloft as it glides through the smog, spraying chemicals that freeze the pollutants in the air and cause them to fall to the ground.

© microdrones

"THEY RACE AROUND THE TREE TRUNKS IN FORESTS IN THE MIDDLE OF NOWHERE "

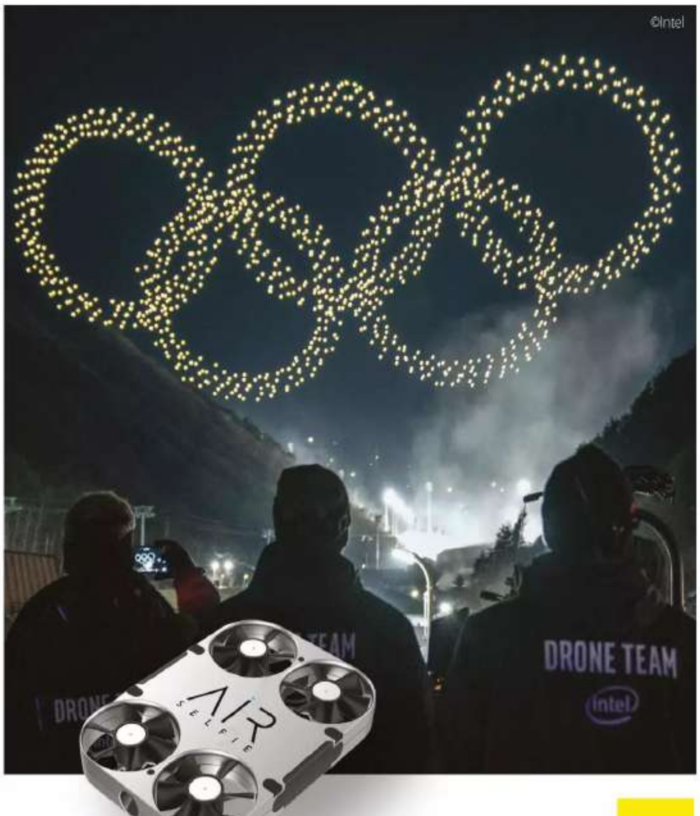
©Jason Om, ABC News

9. RACING

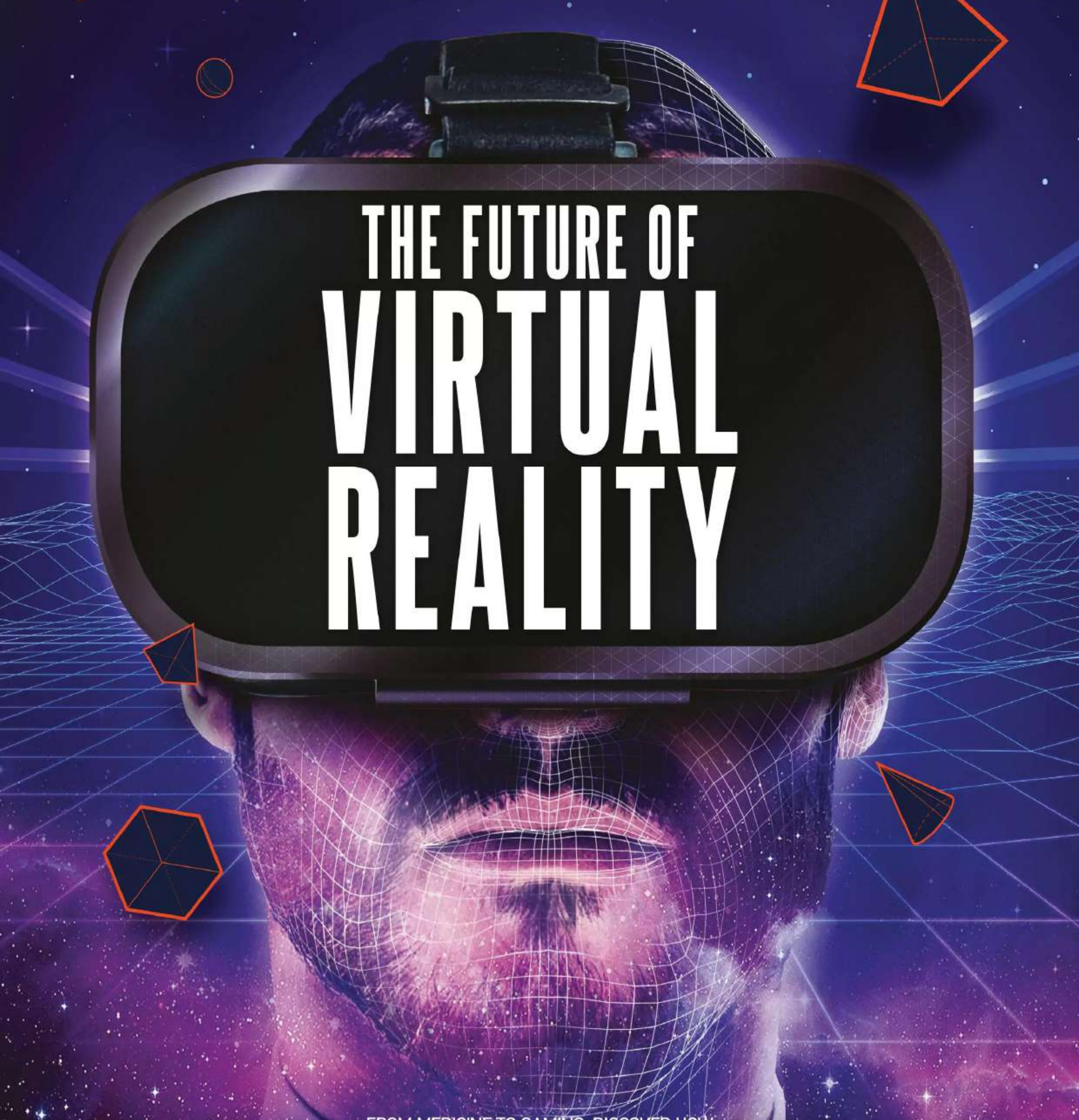
In abandoned warehouses or car parks, pilots race their custom-built multirotor rigs around obstacles. Many use First Person View (FPV) goggles to navigate their drone around the course via its on-board camera, taking skills they've honed on their video console into the real world. Craig Jump from Sky View Video has been involved in a consultation with the BBC about developing a drone-racing TV show. He explains: "This is something that's taken off in the last six months, as low-cost kit came in. At night, they race around the tree trunks in forests in the middle of nowhere." For more on purchasing indestructible sports drones, visit gameofdrones.com.

10. CREATING ART

Drones have inspired musicians to include them as key components in creative projects. In 2015, British rock band Muse released a concept album entitled Drones, about how "the world is run by Drones utilizing Drones to turn us all into Drones". During the opening ceremony of the 2018 Winter Olympic Games in Pyeongchang, 1,218 drones took to the sky, lit up and formed the shape of a snowboarder before turning into the Olympic rings. This set the Guinness World Record for most drones used in a performance. The drones were controlled by a team of animators from the company Intel, who created a routine that was sent to the drones to perform autonomously .



©Intel



THE FUTURE OF VIRTUAL REALITY

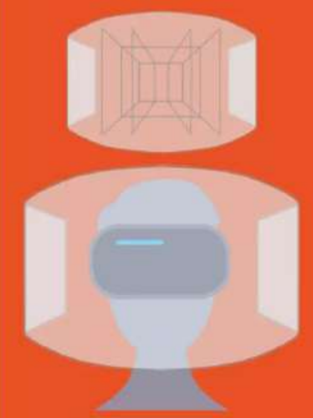
FROM MEDICINE TO GAMING, DISCOVER HOW VIRTUAL ENVIRONMENTS ARE CHANGING THE WORLD

Your first thought about virtual reality (VR) is probably that it's a great way to play new types of games, and that's certainly true. From holodeck-like experiences to immersive mixed reality, there's never been a better time to be a virtual reality gamer. But it's not just entertainment that VR is changing – a host of new fields are finding ways to make the most of this technology, and there are plenty of exciting future applications.

For example, can you imagine the classroom of tomorrow? If you don't have access to a decent education, then virtual classrooms could be a way to learn from teachers around the world. School trips are revolutionised too when you can visit any destination instantly. VR can also be a way for you to meet and interact with friends who live far away, or learn how to operate a piece of machinery that you're finding particularly difficult. Get ready, because thanks to this invention, the future is going virtual.

VR vs AR vs MR

THEY ALL SOUND SIMILAR, BUT HOW DO THESE THREE ACTUALLY DIFFER?

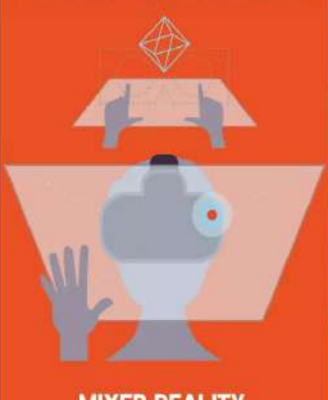


VIRTUAL REALITY

Virtual reality involves using a headset to view a virtual world, perhaps a computer-generated one or a 360-degree video. Using visuals and sound, VR transports you to another environment.

AUGMENTED REALITY

While VR is a virtual world, augmented reality overlays digital information on the real world with a smartphone or other device. This can be used for entertainment or practical purposes.



MIXED REALITY

Mixed reality mixes both the virtual and real world. It allows you to hold and touch physical objects, but they are digitally changed to appear as something entirely different through a headset.

VR KIT

WHAT YOU NEED TO GET STARTED IN A VIRTUAL WORLD

The Dexmo glove helps users to 'feel' objects in virtual reality

HEADSET

A headset, such as the Oculus Rift, contains a screen and headphones to transport you into another environment.

BACKPACK

Wearable computers, like the HP Z VR Backpack PC, are compatible with many VR headsets and provide users with more freedom of movement.

ENDLESS POSSIBILITIES

From games to concerts to distant lands, virtual reality can take players or viewers to fantastical destinations, as well as assist with education and work projects.

HAPTIC GLOVES

Haptic gloves like the VRgluv give you feedback when holding objects in the virtual world, making them feel real.

HAPTIC SUIT

Haptic clothing, such as the Teslasuit and Disney's Force Jacket, can provide real-time feedback to simulate physical effects such as getting 'shot' or 'punched' in a game, or even changing your temperature.

TREADMILL

The Virtuix Omni is an omnidirectional treadmill that allows you to move freely in a 360-degree virtual environment.

Virtual reality technologies are creating an entirely new education experience

EDUCATION

FROM VIRTUAL FIELD TRIPS TO NEW WAYS TO LEARN, HOW VR CAN CHANGE THE CLASSROOM OF THE FUTURE

The kids stare in awe as their teacher shows them the Colosseum in Rome, pointing out details of interest as two gladiators battle below. They see how it looked two millennia ago but also how it looks today and the efforts that have been made to restore it. But the children are not really there; their teacher is showing them this impressive structure thanks to VR.

Using just a smartphone and a cheap headset, each child can be transported to a distant location. One could argue there is no replacement for the real thing, but for children far away or those from underprivileged backgrounds, VR offers a new way to explore exciting destinations.

This is just one way that VR is already being used in classrooms today, allowing for more immersive lessons and giving kids a hands-on experience. As the costs of VR have lowered, more schools have been able to invest in the technology. Other uses include drawing mathematical functions in the virtual world or showing physics principles at work.

In the near future we may see virtual classrooms springing up, bringing education to people that would otherwise not be able to access it. From all over the world children could tune in to a lesson, and with the power of VR, they could learn anywhere.

With the Microsoft HoloLens, teachers can use augmented reality to bring scientific principles to life

VR can also be used to teach people new skills safely, such as operating a train

SOCIAL MEDIA

CAN OUR ONLINE INTERACTIONS BE MADE EVEN MORE SOCIABLE?

One criticism of virtual reality is that, at times, it can be somewhat lonely, but combining it with social media could bring a rather unique spin. With a headset, you can join friends in a shared room in any locale you can imagine, show them your next holiday destination, or even just give them a tour of your new house. Technology like this already exists in the form of programmes like Facebook Spaces, which lets you create shared social chatrooms with friends.

Another exciting step is the plan to introduce virtual reality venues, letting you enjoy concerts, sports and other events even if you aren't able to get a ticket to attend in person. VR is also opening up a potential way to help people with social anxiety, introducing them to safe chatrooms with other people where they can have a social experience without the pressure of being there in person.

ADVANTAGES FOR SOCIAL MEDIA

Hang out with distant friends

Attend events virtually

Help with social anxiety

Facebook Spaces allows users to create an avatar and interact with others in VR

ADVANTAGES FOR EDUCATION

Virtual field trips

Remote classrooms

INDUSTRY

VR IS OPENING A RANGE OF DOORS WHEN IT COMES TO INDUSTRY

All three of virtual, augmented and mixed reality find themselves playing a role in industry. One of the benefits of VR is that it allows engineers to see a finished product before it is built, such as a car. While they can study the car in 3D and see how it looks and functions, customers can be given a virtual tour of the vehicle without setting foot in it.

Another use for VR is training. Companies like STRIVR use VR to put a learner into an immersive environment, meaning they can learn by doing. Other companies like NASA use VR to train astronauts, letting them feel their way around the exterior of the ISS without actually being there.

Augmented reality, meanwhile, can be used in places like warehouses, allowing workers to easily locate objects and packages with the help of smart glasses. Learning how a machine works can also be much easier in AR, with users able to see where different components go or how it fits together, and mixed reality could take this to another level.

Using devices like Microsoft's HoloLens, workers can perform tasks like spotting cracks in bridges without actually being there. MR can also be used to let people step inside new constructions and see the building process taking place, even making suggestions or alterations based on what they can see or feel. Some more novel applications include being able to go shopping and try on clothes without needing to be in the store in the first place.

Designs and alterations can be tested virtually before they are implemented

ADVANTAGES FOR INDUSTRY

"WITH AR YOU CAN SEE WHERE DIFFERENT COMPONENTS GO OR HOW A MACHINE FITS TOGETHER"

TRAVEL

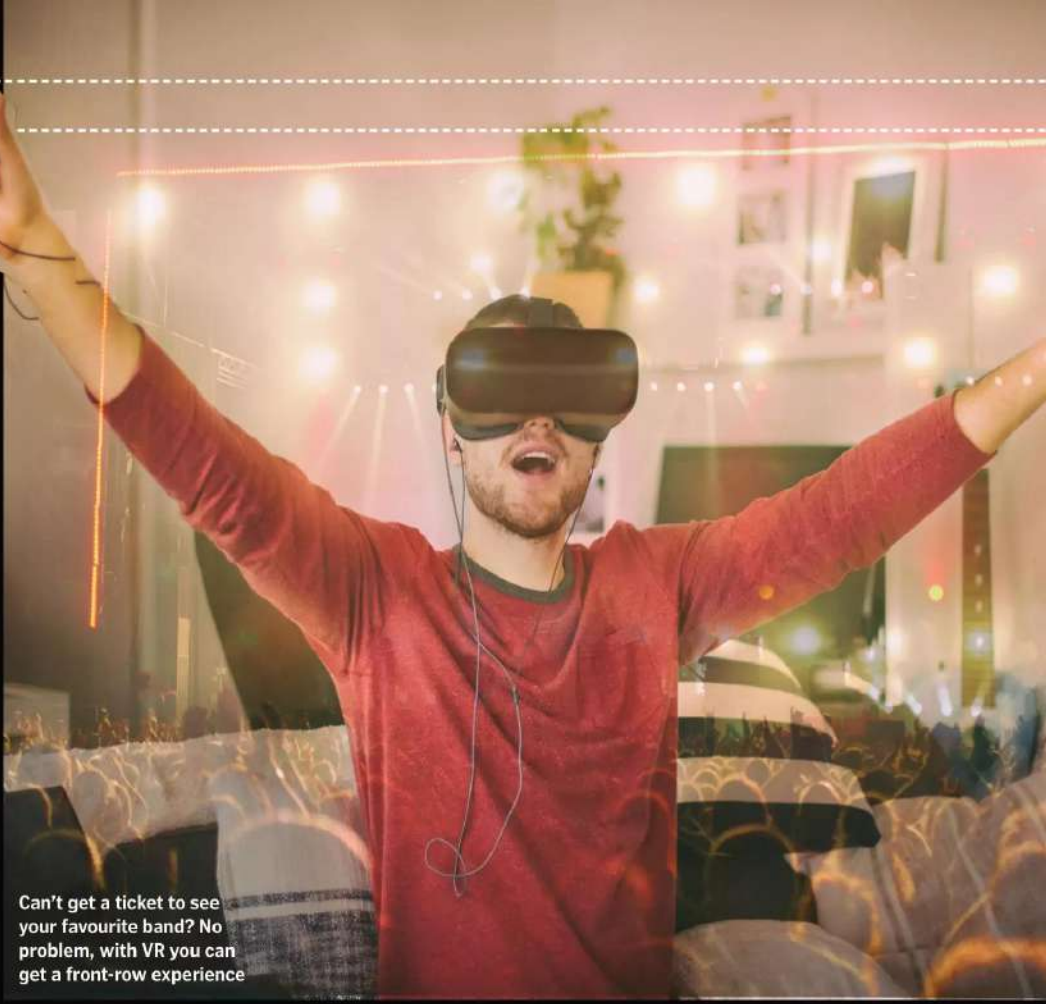
WHILE NOTHING BEATS THE REAL THING, YOU CAN START GETTING PRETTY CLOSE IN VR

You've probably already used a type of VR travel, and you might not have known it. Google Street View has been around since 2007 and enables people to explore towns, cities and even whole countries virtually. But as VR headsets become more available, we're moving on to entirely new capabilities.

For example, some hotels are giving headsets out to guests to let them see the sights before heading out. Museums have also started offering virtual tours in case you aren't able to visit in person. Meanwhile, some planes and trains have introduced a type of mixed reality so that you can 'see' outside of the vehicle while remaining inside.

For more extreme environments, VR offers an attractive way to experience sights few have witnessed, such as Everest VR, which allows you to see what it's like to climb Mount Everest. Augmented reality, meanwhile, can bring historic destinations to life, letting you wander ancient streets and ruins. And with mixed reality you can even bring distant locations into your living room, complete with exotic animals jumping on your furniture!

ADVANTAGES FOR TRAVEL



Can't get a ticket to see your favourite band? No problem, with VR you can get a front-row experience

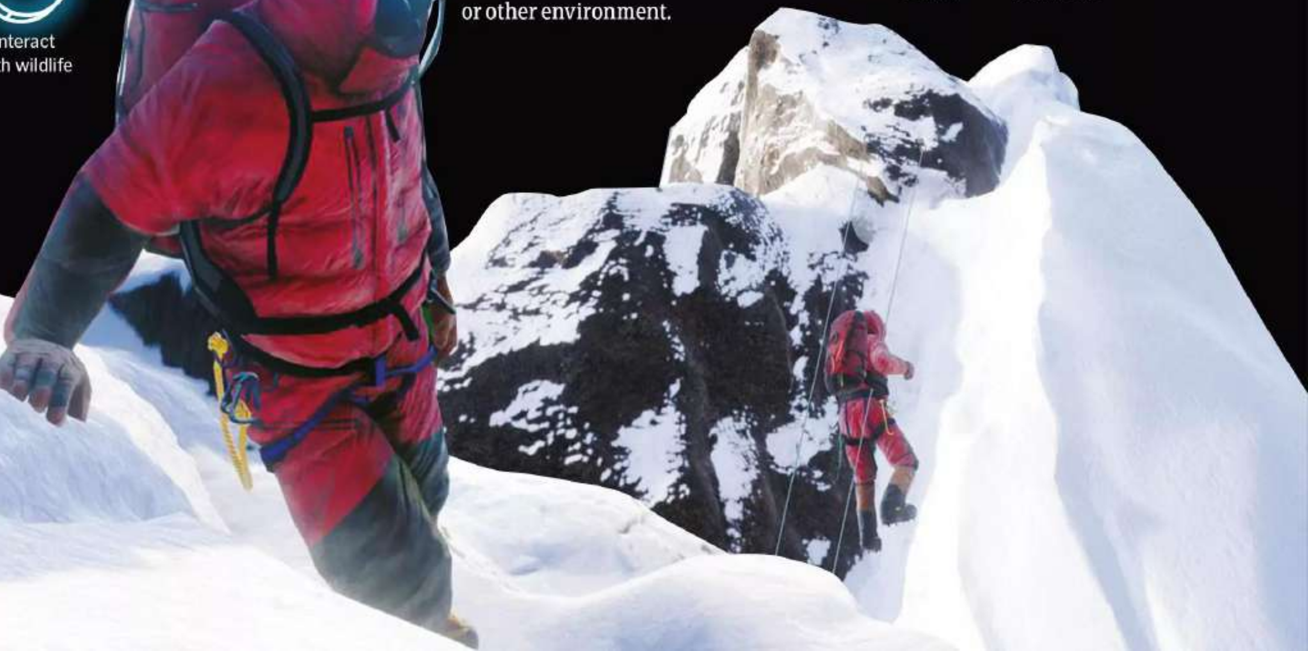
ENTERTAINMENT

PLENTY OF NEW AND FUTURE IMMERSIVE EXPERIENCES ARE READY TO ENTERTAIN YOU

Perhaps no other area has been touted more in terms of the potential of VR than entertainment. From video games to movies, people are finding whole new ways to have fun, such as placing yourself in the seat of a race car, or fighting your way through an alien spaceship. Some of the more novel uses in terms of gaming involve mixed reality. Companies like The Void offer experiences where you can explore seemingly blank rooms, but with the power of MR you are transported holodeck-like to a spaceship or other environment.

MelodyVR and NextVR, meanwhile, offer you a way to watch shows and concerts without having to leave the comfort of your own home. And we've already seen a wave of augmented reality games, such as Pokémon Go, that let you use your smartphone to 'catch' Pokémon in the real world.

ADVANTAGES FOR ENTERTAINMENT



Tag along for a climb up Mount Everest in virtual reality

HEALTHCARE

HOW VIRTUAL REALITY IS TRANSFORMING HEALTHCARE FOR THE BETTER

Having trouble learning a tricky surgical procedure, but there's no expert available? No problem – thanks to virtual reality you can practise an operation before you get anywhere near the operating table, or even brush up on human anatomy. VR is already revolutionising healthcare, and there's only more to come. Doctors and nurses around the world can get training that might not otherwise be available to them thanks to the arrival of cheap VR headsets. For those that can't attend an operation to see a surgeon in action, this training can be vital.

However, it's not just professionals who are benefitting, as patients are getting entirely new treatment options thanks to VR. Virtual therapy can help amputees overcome phantom limb pain from a missing arm or leg by letting them control a virtual version of the limb. Playing simple games in VR, meanwhile, can help people to perform physical therapy exercises during rehabilitation after an accident or injury.

If you have a debilitating phobia, VR treatment can be used to slowly ease you into facing your fear, such as overcoming a terror of heights or spiders. VR can also be used to help autistic people, encouraging a calming effect as they interact with virtual people or animals rather than toys.

One interesting application is that VR can be used to design better hospital layouts, helping patients find where they need to go without relying on staff to step away and take them. It can also be used to help people suffering post-traumatic stress disorder (PTSD), taking them back to a harrowing experience and easing them into the realities of what happened. And let's not forget that VR offers a novel way for patients just to relax and have fun in hospital when recovering.

ADVANTAGES FOR HEALTHCARE

Practising surgical techniques

Help patients with rehabilitation

Help to treat phobias and PTSD

Surgeons can see exactly how to perform a particular operation in VR

AR makes it far easier to study anatomy and plan bespoke treatments for patients

"THANKS TO VR SURGEONS CAN PRACTISE TRICKY PROCEDURES"

Medical students can train with virtual surgery platforms, such as Osso VR

HOW DOES VR WORK?

THE KIT THAT TRANSPORTS YOU INTO VIRTUAL WORLDS

Several mobile headsets that require your smartphone to work are already available, but it's the high-end connected kits that will really show off what VR can do. Oculus and HTC Vive are the current front-runners, with the former gearing up to release their latest version, Oculus Quest, in Spring 2019. These headsets feature built-in displays, are powered via a cable and require external sensor systems to track your movements.

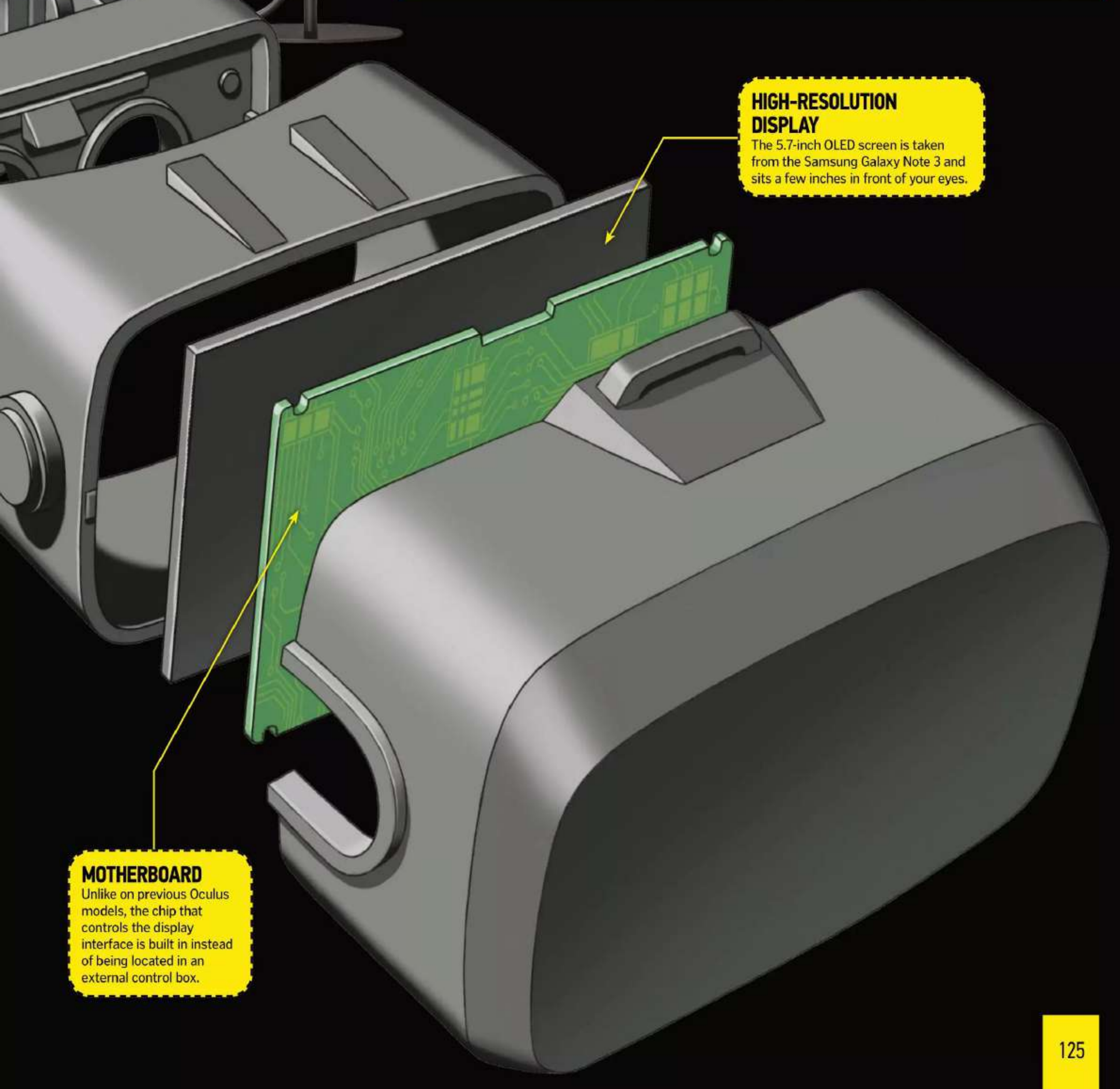
"A SPLIT-SCREEN DISPLAY PUTS A SLIGHTLY DIFFERENT IMAGE IN FRONT OF EACH EYE"

With adjustable straps, the VR headset can be made to fit everyone

OPENING THE RIFT

HOW DOES THE OCULUS HEADSET PUT YOU INSIDE THE GAME?

You don't need much to get started in VR



SPACE

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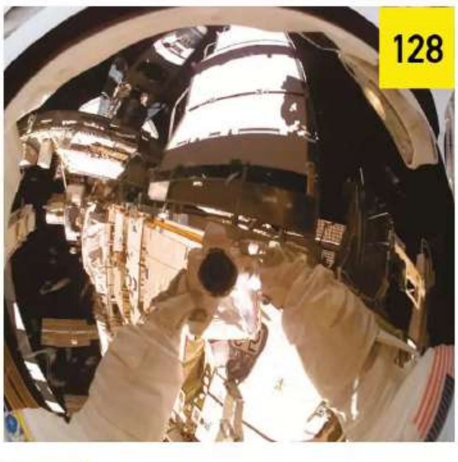

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10 NASA INVENTIONS IN YOUR HOME

BOUND BY ITS MOTTO 'FOR THE BENEFIT OF ALL', SINCE ITS FORMATION NASA HAS HAD AN OBLIGATION TO FOSTER AND TRANSFER ITS TECHNOLOGICAL AND SCIENTIFIC BREAKTHROUGHS TO THE PUBLIC AND COMMERCIAL SPHERES. HOW IT WORKS TAKES A LOOK AT SOME OF THE RESULTANT INVENTIONS YOU CAN FIND IN YOUR VERY OWN HOME

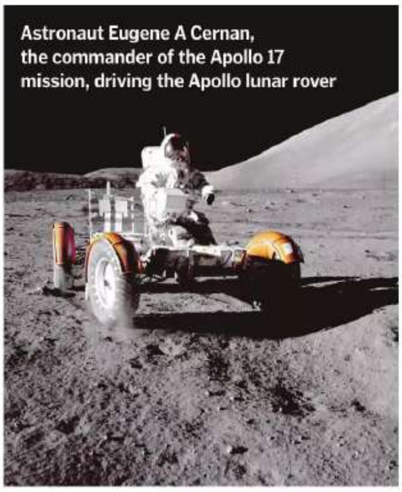
Many tools, machines and facilities within your own home have their origins in research undertaken by NASA over the past 40 years. Technology originally designed to aid space exploration and to land a human on the moon – an endeavour instigated by US President John F Kennedy back in 1961, when he announced a series of exciting new missions including the Apollo Space Program – has been successfully and creatively spun-off to create some of the staple, day-to-day products we now take for granted. From golf balls to gamepads and computers to crash helmets, NASA's technology has been picked up and adapted by specialist companies who have brought it into the public commercial sphere, delivering new and revolutionary products that have transformed how people live their lives and interact with their environment.

Throughout these six pages, we are going to delve deep into the NASA archives to discover the innovative research and inventions that made ten of the most common, everyday household products possible.

6. WATER FILTERS
Designed in the mid 1960s to keep water on board spacecraft pollutant free.

7. MODERN GOLF BALLS
Exists thanks to NASA's research in 1981 into drag-resistant surfaces.

5. MYTH BUSTER - GPS
While GPS technology is commonly credited to NASA, it did not actually invent it.



Astronaut Eugene A Cernan, the commander of the Apollo 17 mission, driving the Apollo lunar rover

© NASA

JOYSTICKS

Spin-off from: Apollo lunar lander
Mission: Apollo 15-17 Date: 1971

As with smoke detectors, joysticks already existed before NASA picked up the technology, but they were unrecognisable to the products we see today. Indeed, it was only through NASA's work on joystick technology as a control mechanism for its Apollo lunar rover – which would be used in the last three Apollo missions to the moon – that we have the digital joystick and thumbstick technology we see in cars, planes and videogame control pads.
The lunar rover's controller was a T-shaped joystick and worked through a series of motors, four for drive and two for steering. Moving the stick forward powered the rover forward, left and right turned the vehicle left or right, and pulling backwards activated the brakes. Activating a switch on the joystick before pulling back would put the lunar rover into reverse, while pulling the handle all the way back activated a parking brake.

After all that time in space and this is when they invade

Water... better when filtered

WATER FILTERS

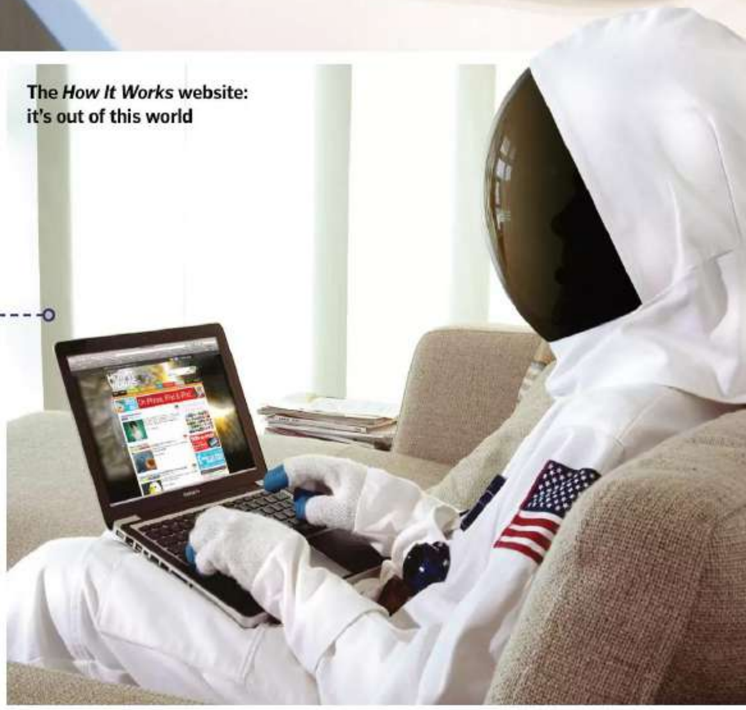
Spin-off from: Spacecraft filtration systems
Mission: Apollo Program Date: 1963-1972

Although water filters had existed in basic form since the mid 1950s, it wasn't until NASA pumped resources into its research for the Apollo Program in 1963 that modern filtration systems began to emerge. NASA led research into this area as large quantities of water would need to be kept uncontaminated for long periods of time in extreme conditions.

To achieve this goal, NASA developed a system that worked by utilising charcoal's ability to absorb (chemically bond with) pollutants and particulate matter present within water when specially treated. This treatment – essentially an oxidisation process that opens up millions of tiny pores between carbon atoms (the charcoal) – amplified the absorbability of the charcoal, which with its large porous surface area provided many sites for pollutants to chemically bond with it through attraction. This left the resultant water clear of impurities.

Buzz Aldrin as imaged by Neil Armstrong during the Apollo 11 mission

© NASA



The *How It Works* website: it's out of this world

MICROPROCESSORS

Spin-off from: Integrated circuits Mission: Apollo Program Date: 1963-1972

Once again, NASA technically did not invent the integrated circuit – which is credited to electrical engineer Jack Kilby in 1958 – but instead invented newer and more advanced variants of it. Indeed, it is easily argued that the NASA's Apollo Program kickstarted the microchip revolution, with the administration buying more than 60 per cent of America's integrated circuits throughout the whole of the 1960s, deliberately allowing the industry to acclimitise itself to mass production and stabilising it while few other markets existed.

One of the first high-profile usages of microchip technology was in the Apollo Guidance Computer with its DSKY interface, which was used to provide on-board computation and control for navigation, as well as control over the command module and lunar module spacecraft.

Today, integrated circuits can be found in almost every area of life, from mobile phones and personal computers to microwaves and calculators, mainly thanks to the cheap processing and manufacture of microchips worldwide.

INVENTION TIMELINE

PROJECT TELSTAR
1962

SATELLITE COMMS
Date: 1962
Better space-to-Earth communications.

APOLLO PROGRAM
1963-72

SCRATCH-RESISTANT LENSES
Date: 1963-72
Protective, scratch-proof visors.

WATER FILTERS
Date: 1963-72
Uncontaminated water on lengthy missions.

MOON BOOTS
Date: 1963-72
Increased Moon walk ease and comfort.

MICROCHIPS
Date: 1963-72
Advanced on-board electronic systems.

CORDLESS TOOLS
Date: 1965
Ability to collect large rock samples.

CRASH HELMETS

Spin-off from: Impact-absorbing foam
Mission: Apollo Program Date: 1966

In 1966, NASA invented temper foam, a shock-absorbing material designed to improve the safety of aircraft cushions. The resultant foam was fitted to the helmets and seats of its Apollo spacecraft, a lining that would help mitigate some of the extreme forces astronauts would be subjected to.

Temper foam is a polyurethane treated with additional chemicals that works as it has both high viscosity and density, properties ideal for absorbing large impacts and resisting energy flow. In addition, the foam is visco-elastic and temperature sensitive, meaning that when pressed against a heat source – such as a human – it moulds to that shape, aiding fit and reducing unwanted gaps.

Temper foam was released into the public sphere in the early 1980s, soon being picked up and utilised in medical equipment such as temper foam mattresses and sports equipment such as American football helmets. Since then the technology has been incorporated into everyday cycle helmets and can be found in many bedroom mattresses and pillows, too.

CORDLESS TOOLS

Spin-off from: Cordless zero-impact wrench
Mission: Project Gemini, Apollo Program Date: 1965

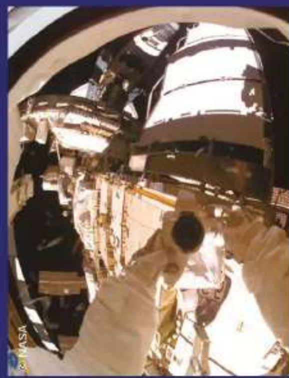
After American President John F Kennedy announced the Apollo Space Program in 1961, a deluge of research commenced into the practicalities of human spaceflight under Project Gemini. One of the most notable breakthroughs was NASA's collaborative invention with tool company Black & Decker into a cordless, zero-impact wrench, a tool that could spin bolts in zero gravity without spinning the astronaut. From this, the research programme developed cordless tools for a variety of purposes, including a cordless rotary hammer drill that could be used for extracting rock samples from the Moon's surface.

These tools worked by exploiting the emerging technology of small-scale rechargeable electrochemical cells, which could be grouped to form a battery pack capable of delivering enough power to generate the requisite amount of torque necessary to bore into the Moon's surface crust. Today, this technology has become common and widespread, with the majority of tools operating off a cordless battery pack that can be recharged between uses. Interestingly, it was directly from the research done by NASA in the 1960s that Black & Decker developed the cordless 'Dust Buster' hand-held vacuum cleaner.

More handyman than spaceman

SCRATCH-RESISTANT, PROTECTIVE LENSES

Spin-off tech: Scratch-resistant spacesuit visors / scratch-proof glass and plastic coatings
Mission: Apollo Program
Date: 1963-1972



An astronaut uses a digital camera to expose a photo of his helmet's visor while performing maintenance on the ISS

After NASA had realised that plastics were a lot better at absorbing ultraviolet light (which can be damaging to the human eye) and did not shatter if dropped, space visors were produced from plastic. However, uncoated plastic easily scratched, and considering the amount of dust and rubble in a space environment (notably while on the Moon, the chief destination of the Apollo Program), it was determined that scratch-proof lenses and coatings needed to be developed.

Due to NASA's research, space visors are now coated with diamond-like carbon (DLC) coatings, that are applied in thin films to the outside of the visor and toughen it massively. Further, an offshoot of this technology is now also available on Ray-Ban sunglasses, while Foster-Grant historically bought the licence to replicate early coatings to apply to its entire range.

IMPACT ABSORPTION FOAM
Date: 1966
Protective cabin and helmet foam.

JOYSTICKS
Date: 1971
Efficient, multi-directional control.

PROJECT GEMINI
1965

SKYLAB PROGRAM
1973

SMOKE DETECTORS
Date: 1973
Improved safety on board Skylab.

SPACE SHUTTLE PROGRAM
1981

DRAG-RESISTANT SURFACES
Date: 1981
Helping golf balls travel further.

SATELLITE TELEVISION

Spin-off from: Satellite communication
Mission: Project Telstar Date: 1962

The first satellite capable of relaying TV signals was Telstar 1. Launched on the top of one of NASA's Thor-Delta rockets in 1962, it was a joint project to develop an experimental satellite communications system over the Atlantic Ocean. The satellite was built by Bell Telephone Laboratories in partnership with NASA.

The satellite worked by utilising a transponder to relay data. It received microwave signals through an omni-directional array of small antennas located around its equator before upscaling and amplifying the signal's frequency in a travelling-wave tube, which amplifies a signal by forcing it to mix with an electron beam within a vacuum tube, causing a bunching of electrons and inducing a higher current build-up, amplifying it as it passes down the device. The waves are then retransmitted to ground stations.

NASA continued to develop this technology in subsequent satellites, producing more advanced systems to reduce noise and errors in transmitted signals, which has led to the ability to transmit HD video and audio.

"Mr... Spock... I... have... a plan"

Freeze-dried foods are now used in everyday cereals

SHOE INSOLES

Spin-off from: Lunar boots
Mission: Apollo Program Date: 1963-1972

The Apollo lunar suit was an incredibly complex system. However, one of the most notable inventions NASA included in its suits was its special three-dimensional 'spacer' material in the boots for cushioning and ventilation.

Used to give astronauts better control, agility and longevity while on their feet, the lunar boot was an overshoe that the Apollo lunar explorer slipped on over the integral pressure boot of the spacesuit. The outer layer of the lunar boot was made from metal-woven fabric, except for the ribbed silicone rubber sole that provided extra springiness and comfort while moonwalking.

Further, the tongue area of the boot was made from Teflon-coated glass-fibre cloth, while the boot's inner layers were made from Teflon-coated glass-fibre cloth followed by 25 alternating layers of Kapton film to form an efficient and lightweight thermal insulation.

From this technology, commercial shoe manufacturers created a series of lightweight, warm and springy running shoes and trainers, which are now on sale worldwide in high street shops.

A boot print on the moon from NASA's Apollo 11 mission. NASA added springy soles and a ventilation system to space suit boots for the Apollo Program

MODERN GOLF BALL DIMPLES

Spin-off from:
Drag resistant surfaces
Mission: Space Shuttle Program Date: 1981

As part of the Space Shuttle Program, NASA undertook research into maximising the drag resistance of its new launch system's surfaces, especially for the external fuel tank. The special dimpled surface applied to the tank allowed NASA to hit a more optimum lift-to-drag ratio, getting more distance and stability out of its launch.

After being released into the public sphere, this aerodynamic coating was studied by the Wilson Sporting Goods Company, where its engineers learned that by applying dimples to the surface of a golf ball, the ball could glide more smoothly with less aerodynamic drag. With special 3D computer graphic software, the Wilson engineers were able to predict the progress made for their new golf ball and designed one with medium-sized dimples that created both high lift and far-gliding potential. Today, all golf balls utilise this dimpled coating technology.

WHAT NASA DIDN'T INVENT…

MYTH BUSTER

TANG

Unfortunately this tasty beverage was not created by NASA, instead being developed by General Foods in 1957. Tang rose to prominence after it was selected for a NASA mission's menu in 1962.

VELCRO

Used by NASA to anchor equipment in zero gravity for the convenience of astronauts, Velcro was not invented in the Apollo Space Program. Contrarily, it was a Swiss invention of the 1940s.

TEFLON

Teflon was actually invented as far back as 1938 by the science company DuPont. NASA's relationship with the material extends to it being used in heat shields, space suits and cargo hold liners.

BARCODES

NASA did not invent the barcode. It did, however, invent a special variant of the barcode to be used to log and categorise the inventory of the Space Shuttle.

QUARTZ CLOCK

Again, this technology is often credited to NASA due to a joint project run in the Sixties to create a highly accurate quartz timepiece. In fact, the quartz clock was invented in 1927.

The Saturn V rocket launch, the carrier for Skylab

© NASA

HOUSEHOLD SMOKE DETECTOR

Spin-off tech: Adjustable smoke detector
Mission: Skylab Date: 1973

The smoke detector, while invented by Francis Robbins Upton in 1890, was not adjustable until NASA invented a model with variable sensitivity in 1973. The units, which were fitted in the space station Skylab, were installed to detect toxic vapours on board that could be hazardous to astronauts.

These new adjustable units worked through ionisation, a process that involves using a small quantity of the radioactive isotope Americium-241 to ionise oxygen and nitrogen atoms in a detector's embedded air chamber, which itself is topped and bottomed with two metal plates attached to the unit's battery. This means that while ionisation occurs – ie the alpha particles of Americium-241 knocking an electron off the oxygen and nitrogen atoms within the chamber – the freed electrons (which have negative charges) are attracted to the plate with a positive voltage plate and the electron-less atom (with a positive charge) to the negative voltage plate, thus creating an electric current.

When smoke particles from a fire enter the air chamber, they disrupt the current as they attach to the ions and neutralise them. The smoke detector senses the drop in current and sets off the alarm.

WITH THANKS
Thanks to the folks at INTECH Science Centre and Planetarium for letting us use their space suit for our NASA inventions photoshoot. For information about what's on at INTECH visit www.intech-uk.com.

HOW THIS MARVELLOUS INVENTION FERRIED ASTRONAUTS TO AND FROM ORBIT FOR 30 YEARS

THE SPACE SHUTTLE

On 12 April, 1981, the Space Shuttle launched into our skies for the first time as the orbiter Columbia lifted off from Cape Canaveral in Florida. This mission, STS-1, was the first in what would be 135 successful missions in 30 years of service. Two terrible tragedies – Challenger in 1986 and Columbia in 2003, both of which lost their entire crews – overshadowed the programme in its later years, but the achievements of the Shuttle were many.

The Space Shuttle was born from a desire to make space more accessible. Following on from the expensive race to the Moon with the Soviet Union, the Shuttle was NASA's attempt to get back on more steady footing. After the US emerged victorious by landing on the Moon in 1969, President Richard Nixon wanted a new direction for NASA. They began to develop the Space Shuttle, a reusable method to reach orbit at what was hoped to be a lower cost.

Originally, NASA had planned the Shuttle to be a fully reusable two-stage vehicle, both piloted on their way to space. Budget cuts, however, led to a still impressive but decidedly clunkier design that did not quite live up to the dream of reusability. The Shuttle launched strapped to a giant tank of fuel, with two side solid rocket boosters (SRBs) attached to give it an extra kick. The orbiter itself was reusable and could land on a runway, but the tank was expendable and the boosters had to be recovered from the sea, where they were damaged by salt.

"THANKS TO THE SPACE SHUTTLE WE COULD BUILD THE ISS"

Despite its flaws, the Shuttle was unique. Previously, astronauts had launched to space in cramped capsules. Here was a roomy vehicle that could launch seven people and with them satellites and other equipment to use or release in orbit. Thanks to the Shuttle we were able to launch and service the Hubble Space Telescope, perform countless experiments in orbit, learn more about human spaceflight than ever before and build the International Space Station.

The Space Shuttle made spaceflight routine in an age where it had been anything but. It flew for the last time in July 2011 when Atlantis completed the STS-135 mission. And although it comes in for some deserved criticism, there's no doubt about its huge impact on space travel.

THREE DECADES IN ORBIT

HOW THIS PIONEERING SPACECRAFT HELPED OPEN UP THE FINAL FRONTIER

FIRST AMERICAN FEMALE ASTRONAUT

Sally Ride became the first American woman to go into space on 18 June 1983. She flew aboard Space Shuttle Challenger on the STS-7 mission, deploying communications satellites and conducting experiments during six days in orbit. Ride flew once more in 1984 but sadly died from cancer in 2012.

FIRST AFRICAN-AMERICAN ASTRONAUT IN SPACE

Guion Bluford became the first African-American to go into space on Challenger's STS-8 mission on 5 September, 1983. This mission released an Indian communications and weather observation satellite. Bluford flew on three more Shuttle missions before leaving NASA in 1993.

1991

LAUNCHING HUBBLE

Arguably the most famous Shuttle mission, STS-31 on 24 April 1990 saw the Hubble Space Telescope taken to orbit. It was deployed a day later in a high orbit 612 kilometres above Earth to prevent it being dragged into the atmosphere.

LONGEST MISSION

STS-80 was the longest Space Shuttle mission, totalling 17 days, 15 hours and 53 minutes. It was flown by Space Shuttle Columbia from 19 November to 7 December 1996. The landing should have been two days earlier but bad weather prevented the Shuttle returning to the runway on schedule.

2001

MICROGRAVITY RESEARCH

More than 20 Shuttle missions were dedicated to low-gravity research in a quest to understand the effects of microgravity on biological, chemical and physical systems. This was done aboard a specially designed Spacelab module, which was used to see how cells responded to flying in space, among other experiments.

FIXING HUBBLE

Four separate servicing missions between 1993 and 2009 kept Hubble working properly. The first replaced its primary mirror, which had been launched with a flaw. No other spacecraft before or after has been capable of such servicing missions.

INSIDE THE SPACE SHUTTLE

HOW THE DESIGN OF THIS VEHICLE ALLOWED IT TO PERFORM GROUNDBREAKING SCIENCE IN ORBIT

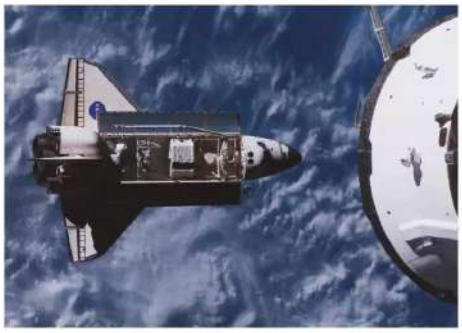
The design of the Space Shuttle incorporated a number of key demands that needed to be met. These included making it highly reliable, able to carry a large variety of cargo and making it as versatile in orbit as possible. Most of these conditions were indeed met, making the large majority of Shuttle flights a success.

One of the Shuttle's key successes was its cargo bay. Using swinging bay doors it was able to accommodate lots of different payloads, from satellites to experiments. The doors were designed to not only be sturdy at launch but also to be opened in space. Crucially, they had to close tightly for re-entry to prevent any hot gases getting inside the vehicle. A zipper-like system ensured that the doors would close even if they were distorted by temperature changes or Earth's gravity.

Another key innovation was the use of the Canadarm, a long mechanical arm that was used to deploy satellites and other tasks. On later missions it was used to inspect the Shuttle for damage following the Columbia disaster, when a hole in the Shuttle's left wing caused it to disintegrate on re-entry in February 2003, tragically killing all seven crew members.

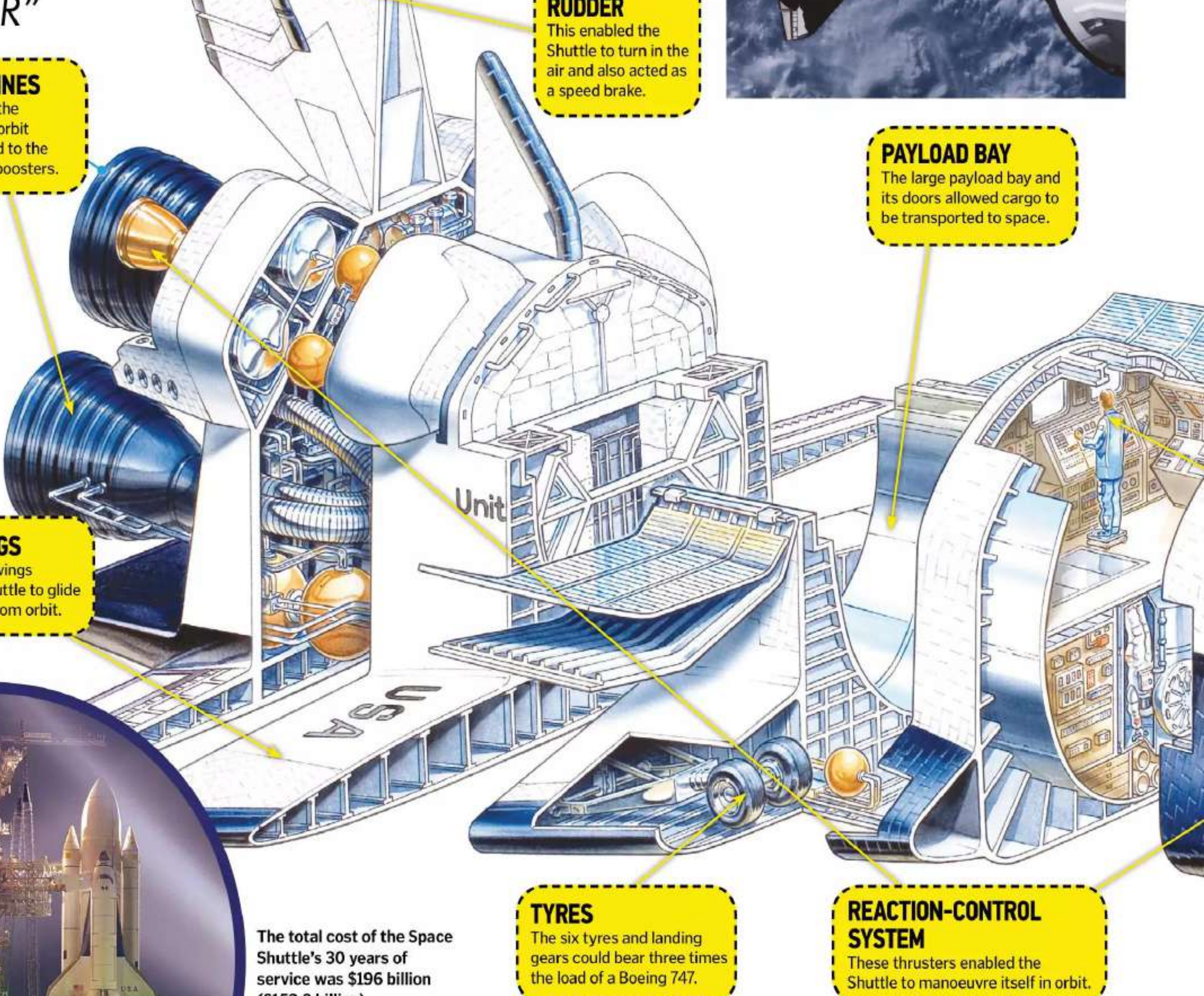
One of the greatest innovations, though, was that the entire Shuttle orbiter was designed to return to Earth as a glider. Because the main fuel tank was jettisoned on the way to orbit, the Shuttle did not have access to propellant during the descent even though its own engines were still attached. Using a low glide angle and a long drift time, the Shuttle was able to return from speeds in orbit of 27,800 kilometres per hour to about 400 kilometres per hour when landing.

"THE SHUTTLE WAS DESIGNED TO RETURN TO EARTH AS A GLIDER"

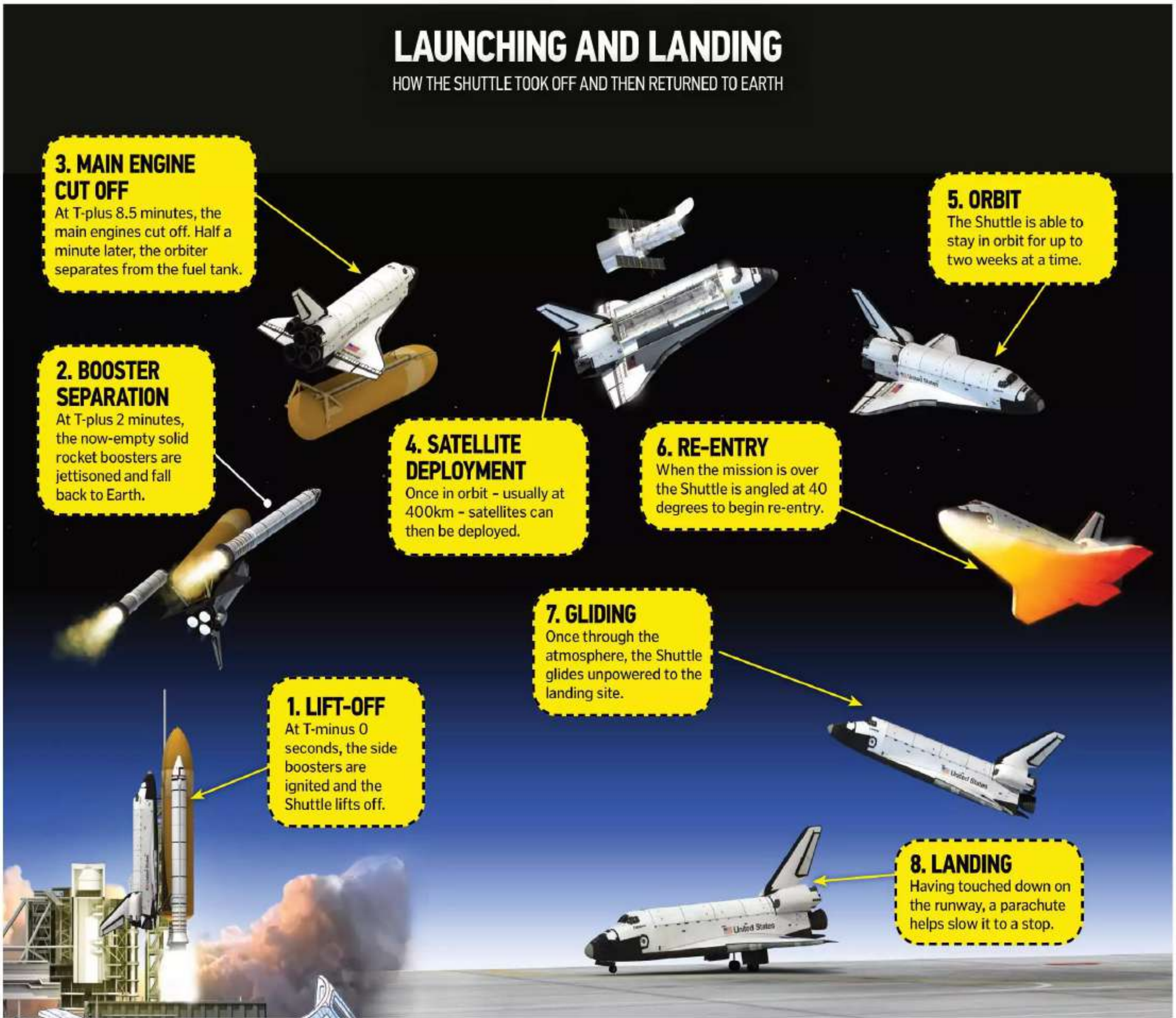


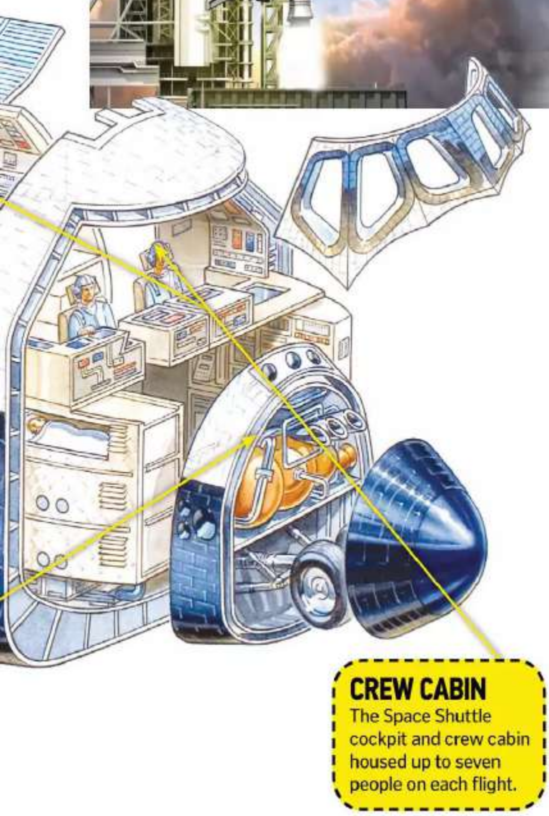
KEY COMPONENTS

THE MAJOR PARTS OF THE SPACE SHUTTLE THAT MADE IT A SUCCESS



The total cost of the Space Shuttle's 30 years of service was $196 billion (£152.2 billion)

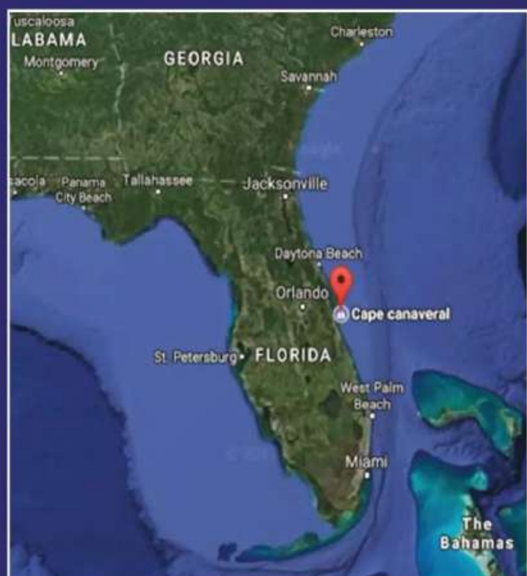




WHY LAUNCH FROM FLORIDA?

Cape Canaveral in Florida has a number of benefits for rocket launches. For one thing, it's relatively close to the equator, which gives rockets a speed boost from Earth's rotation. The rotation on our planet is fastest near the equator, so the closer you are - provided you launch in the same direction as Earth is rotating - the faster your rocket will go.

That's important for another reason. In order to get this speed boost, you need to launch east in the Northern Hemisphere. As many rockets, including the Shuttle, have expendable parts, it's best if you launch over an ocean so that pieces do not fall on the ground. Thus, Florida is ideal as it's on the east coast and also relatively near the equator. Launch pads elsewhere in the world are located in similar positions for the same reasons.



Before moving to Cape Canaveral in July 1950, NASA launched its rockets from New Mexico

MISSION SUMMARY

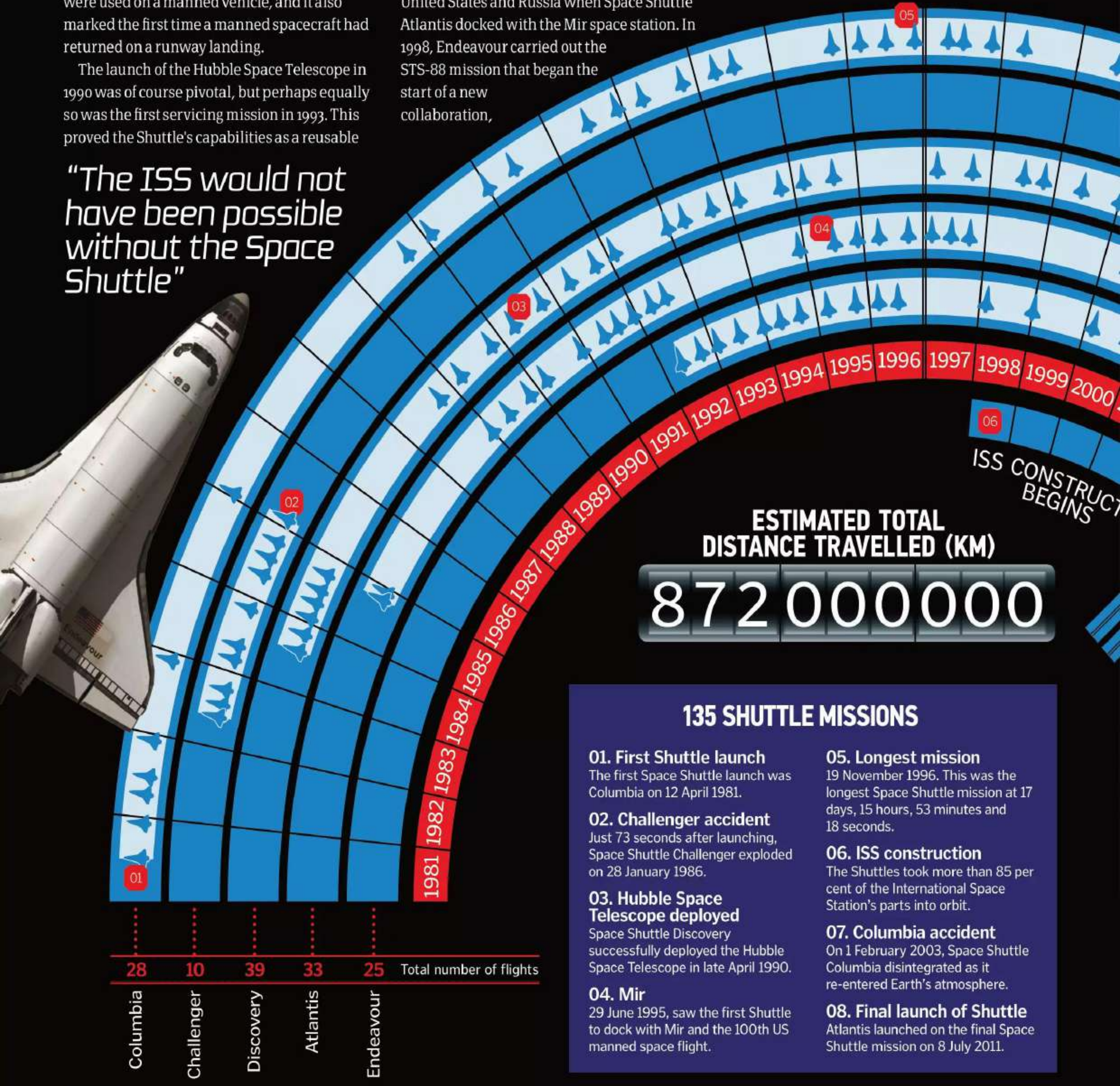
THE TRAILBLAZING MISSIONS THAT MADE THE SHUTTLE A LEGEND

There were 135 Space Shuttle missions that successfully made it to orbit. All of these performed some incredible science. The inaugural launch of Space Shuttle Columbia on 12 April 1981 was no doubt one of the most important, and it achieved a number of firsts. It was the first time solid rocket boosters (SRBs) were used on a manned vehicle, and it also marked the first time a manned spacecraft had returned on a runway landing.

The launch of the Hubble Space Telescope in 1990 was of course pivotal, but perhaps equally so was the first servicing mission in 1993. This proved the Shuttle's capabilities as a reusable spacecraft that could repair satellites in orbit. STS-93 in 1999 was also important as it launched the Chandra X-ray Observatory, which has helped us study supernovae, nebulae, black holes and more.

Just prior to that in 1995, the STS-71 mission heralded a new era in partnership between the United States and Russia when Space Shuttle Atlantis docked with the Mir space station. In 1998, Endeavour carried out the STS-88 mission that began the start of a new collaboration, the construction of the International Space Station (ISS). The final mission, STS-135, launched on 8 July 2011, was a sombre one as it brought the programme to a close. Atlantis delivered two major components to the ISS and brought to a close one of the greatest technological achievements of our time.

"The ISS would not have been possible without the Space Shuttle"



135 SHUTTLE MISSIONS

01. First Shuttle launch
The first Space Shuttle launch was Columbia on 12 April 1981.

02. Challenger accident
Just 73 seconds after launching, Space Shuttle Challenger exploded on 28 January 1986.

03. Hubble Space Telescope deployed
Space Shuttle Discovery successfully deployed the Hubble Space Telescope in late April 1990.

04. Mir
29 June 1995, saw the first Shuttle to dock with Mir and the 100th US manned space flight.

05. Longest mission
19 November 1996. This was the longest Space Shuttle mission at 17 days, 15 hours, 53 minutes and 18 seconds.

06. ISS construction
The Shuttles took more than 85 per cent of the International Space Station's parts into orbit.

07. Columbia accident
On 1 February 2003, Space Shuttle Columbia disintegrated as it re-entered Earth's atmosphere.

08. Final launch of Shuttle
Atlantis launched on the final Space Shuttle mission on 8 July 2011.

FIVE KEY STATS

238.5mn km

The distance covered by Space Shuttle Discovery, which travelled the furthest of all five Shuttles during its service.

100,000kg

The approximate weight of the Shuttle orbiter upon its re-entry into the Earth's atmosphere.

2mn kg

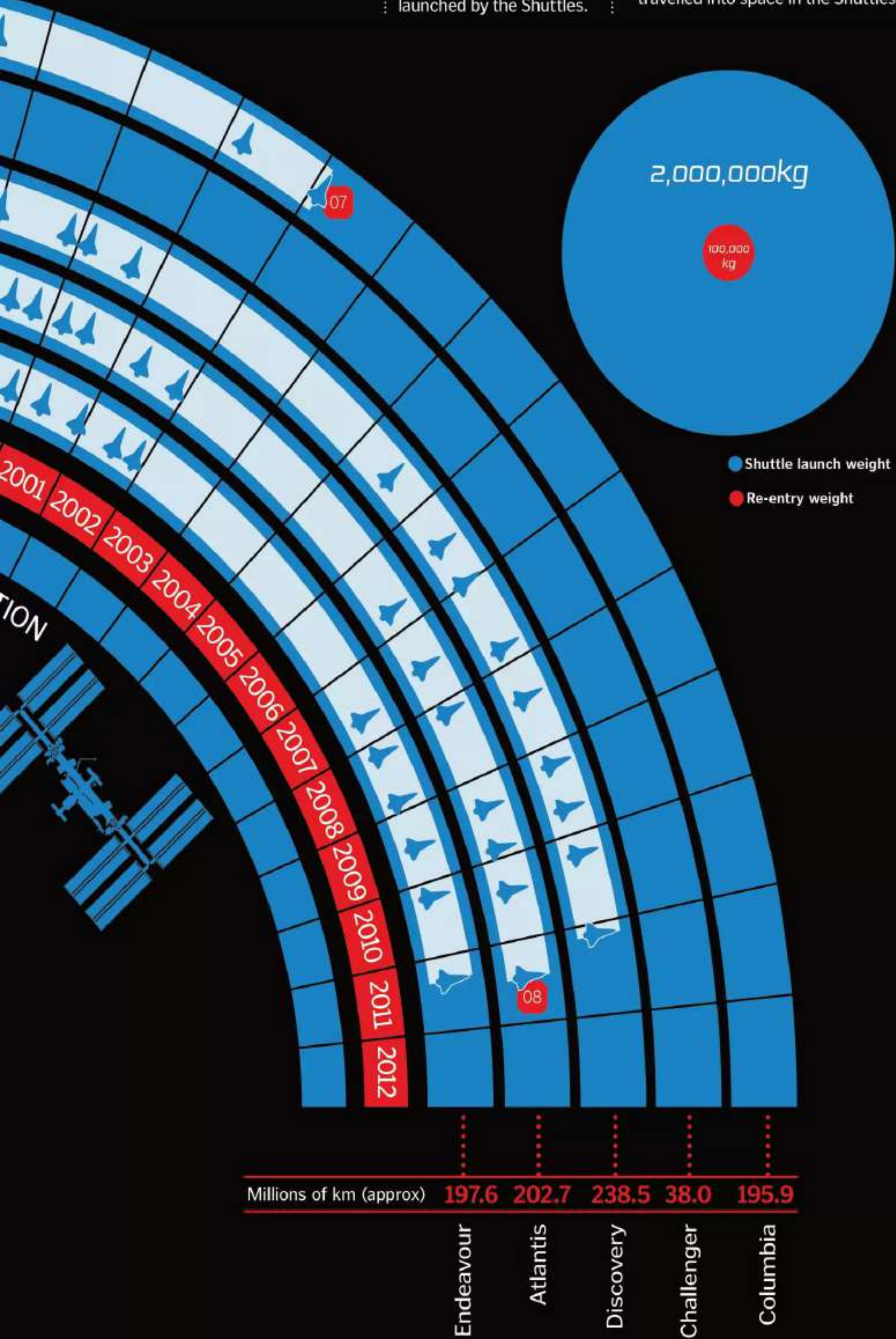
The combined weight of the Shuttle, boosters and tank at launch.

Over 85%

The proportion of the ISS's structure that was launched by the Shuttles.

600

The number of astronauts that travelled into space in the Shuttles.



THE SHUTTLE'S LASTING LEGACY

WHILE THE SHUTTLE HAS NOW GONE, IT HAS LEFT BEHIND A SHINING LEGACY OF EXPLORATION

INTERNATIONAL SPACE STATION

The ISS is one of the greatest human-made constructions of all time. This vast $100 billion (£79.2 billion) station spans the size of a football pitch and has been continuously manned since 2000. It was assembled in space, and its construction arguably would not have been possible without the Space Shuttle. Today, astronauts continue to work on the ISS and conduct groundbreaking research not only into spaceflight, but also into areas that improve our lives here on Earth.

HUBBLE SPACE TELESCOPE

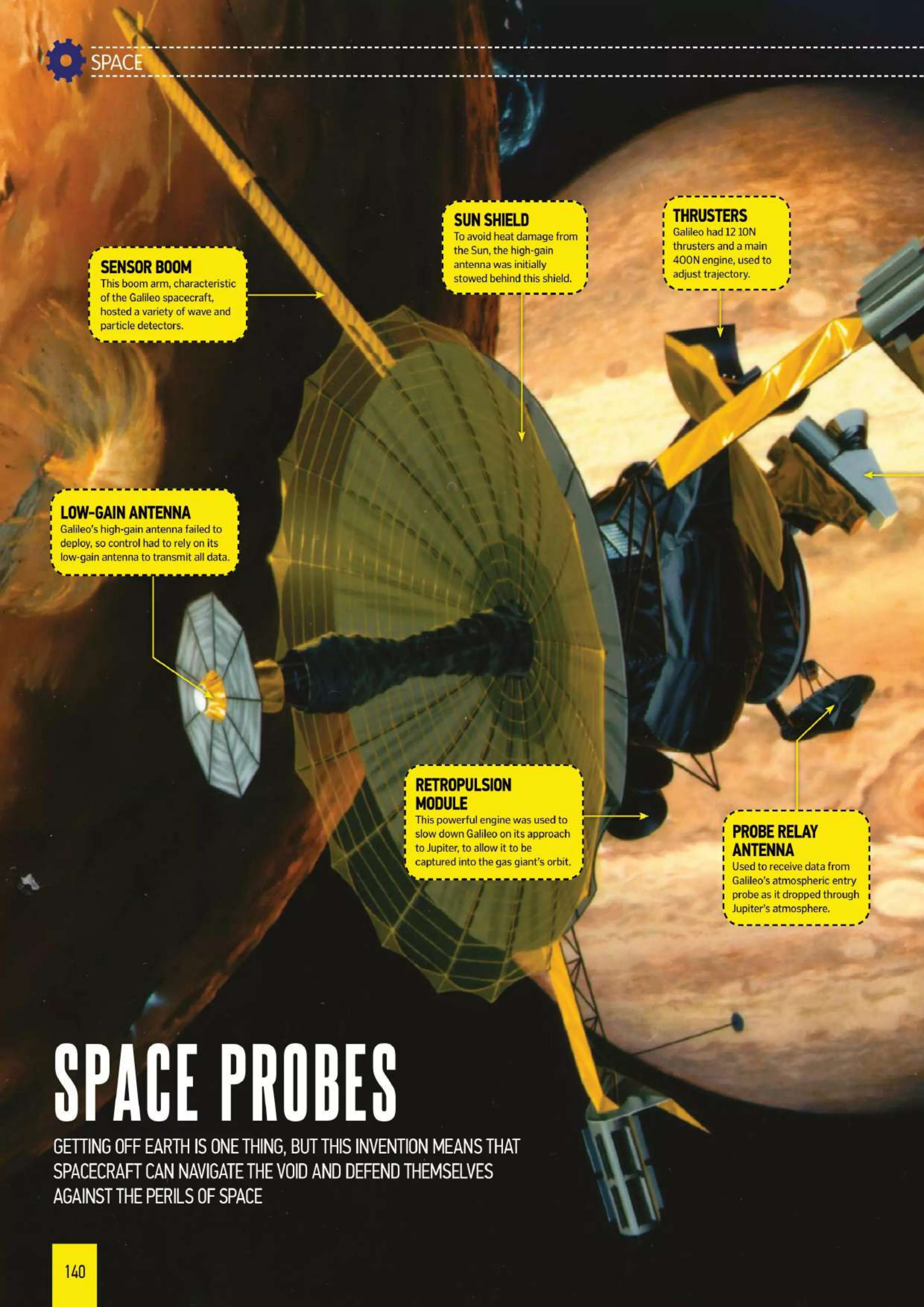
Since its launch in 1990, the Hubble Space Telescope has made countless discoveries. It has peered into the distant universe and found galaxies stretching back to just 400 million years after the Big Bang. It's taken Deep Field images of the cosmos, revealing a vast number of galaxies, and closer to home it has found water bursting from Jupiter's moon, Europa. Still going strong, who knows what the Hubble will find next?

CHANDRA X-RAY OBSERVATORY

Still operational today, the Chandra X-ray Observatory is one of NASA's 'Great Observatories' along with Hubble, the Gamma Ray Observatory and the Spitzer Space Telescope. Launched on Columbia in 1999, it has observed the universe in X-rays to help astronomers see into the centre of a supernova. It has found a galaxy being eaten by another and also observed the X-ray emissions from the supermassive black hole at the centre of our galaxy.

MICROGRAVITY RESEARCH

Thanks to the Shuttle, we were able to perform some fascinating microgravity research in orbit that still has impacts today. It proved that cells could grow in microgravity, even with a lack of fluid mixing due to gravity. Experiments also discovered that some immune cells were not as effective while in microgravity, which has implications for long-duration space travel. And it also helped test the limits of how humans can operate in space.



SPACE PROBES

GETTING OFF EARTH IS ONE THING, BUT THIS INVENTION MEANS THAT SPACECRAFT CAN NAVIGATE THE VOID AND DEFEND THEMSELVES AGAINST THE PERILS OF SPACE

SPACECRAFT ENGINEERING

WHAT TECHNOLOGY DID THE GALILEO SPACECRAFT USE TO REACH JUPITER AND STUDY IT IN DEPTH?

RTG
Two radioisotope thermoelectric generators (RTGs) supplied Galileo's subsystem power.

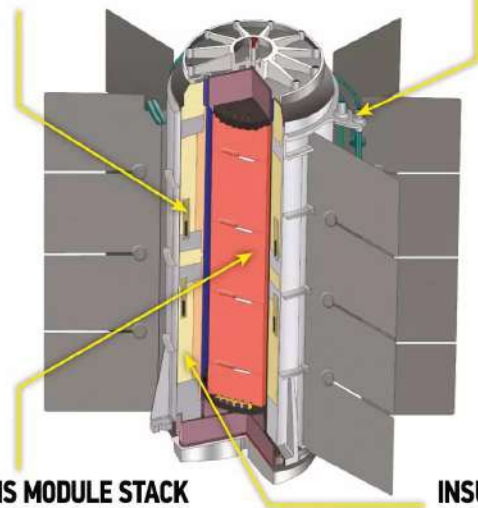
SCAN PLATFORM
Many key instruments on the Galileo mission were housed here, including a UV spectrometer and solid-state camera.

MULTI-MISSION RADIOISOTOPE THERMOELECTRIC GENERATORS

USING THE NATURAL DECAY OF PLUTONIUM-238 DIOXIDE, MMRTGS ARE A RELIABLE SOURCE OF LONG-TERM POWER

THERMOELECTRIC MODULE
One of two modules that use this thermal energy to heat the hot junction of the thermocouple in order to generate electricity.

COOLING TUBES
The MMRTG is integrated with a chiller and pumping unit that flows coolant around the casing and fins via a series of tubes.



GPHS MODULE STACK
Eight general-purpose heat source (GPHS) modules contain the radioactive isotope that creates heat.

INSULATION
Space is extremely cold, so it's vital to ensure the thermal energy produced by the GPHS modules doesn't immediately radiate away.

The word 'spacecraft' usually evokes an image of a 'warp-speed'-travelling vessel of the future, but in the broadest definition, they're any vehicle designed for travel in space, either piloted or unmanned. In the past few decades since we've learned how to escape Earth's gravity, we've sent hundreds of spacecraft off to many of the major destinations in the Solar System, from our own Moon and the Sun, right out to dwarf planet Pluto and the very border of interstellar space.

While the Vostok manned space programme and Apollo missions to the Moon required life-support systems for the astronauts on board, sending unmanned craft into space is far from simple by comparison. Depending on the mission type and the target destination, the challenges of deep space and hazards encountered can threaten the craft's main systems or damage the sensitive science instruments it carries, potentially rendering the mission a failure.

A probe, lander, orbiter or any of the broad categories a spacecraft can fall under will house bespoke technologies specific to its mission, but they all require a power supply and energy distribution to keep their systems and instruments running. Power is a premium commodity, especially for those missions that run over decades like the Voyager and New Horizons probes. Chemical fuel cells, solar power, batteries or a radioisotope thermoelectric generator (RTG) all might be used as an energy source. Via careful monitoring both from ground control on Earth and by the spacecraft's main computer, power to any individual system can be shut down to keep the electrical outlay within the limits of the supply.

The on-board computer isn't just there to keep tabs on power though. This will process all of the data from instruments, interpret signals from mission control and, vitally, maintain several levels of fault protection, helping to prevent all manner of problems, from minor malfunctions to those that can jeopardise the entire mission. As a fundamental component of any computer, the craft will also contain a clock by which all activity is regulated.

TYPES OF SPACECRAFT

1 FLYBY
Examples:
Voyager 1, Pioneer 11
These craft are on a trajectory that avoids being captured into an orbit of a planet. They have to be capable of surviving decades of travel.

2 ORBITER
Examples:
Galileo, Mars Global Surveyor
Designed to reach a planet or moon and insert itself into its orbit. These are equipped with thermoregulatory systems enabling them to cope with long exposure to hot sunlight as well as extreme cold in the shade.

3 ATMOSPHERIC PROBE
Examples:
Huygens, Galileo probe
These probes are ejected from the main spacecraft in a close approach to a planet and drop through its atmosphere on a parachute, recording and transmitting data as they go.

4 BALLOON PACKAGE
Examples:
European Venus Explorer, Vega 1
Similar to the atmospheric probe, only it's suspended in the atmosphere with a bag of gas so it can study wind patterns and atmospheric composition over a set period.

5 LANDER
Examples:
Viking, Venera series
A lander also drops through the atmosphere via a powered descent or parachute. Once on the surface, it is protected from environmental extremes (like immense atmospheric pressure) to survive long enough to deploy instruments and transmit data.

Around half a dozen subsystems control a spacecraft's propulsion, attitude and articulation. A main engine produces the force necessary for a motor burn or orbit insertion, with rocket fuel or propellant. Thrusters are much smaller devices that can nudge a craft back on course or make other correctional manoeuvres. Controlling the orientation of the craft is important not just to maintain its trajectory, but also to provide the ideal position for communicating with Earth, pointing instruments in the right direction, and to use both sunlight and shadow for thermal control.

The extreme conditions of the Solar System mean any spacecraft needs to be equipped with environmental subsystems to deal with many dangers. Colliding with an asteroid is probably of least concern: even if a spacecraft is travelling through the Asteroid Belt, there are millions of kilometres between each one so the odds of a crash are negligible.

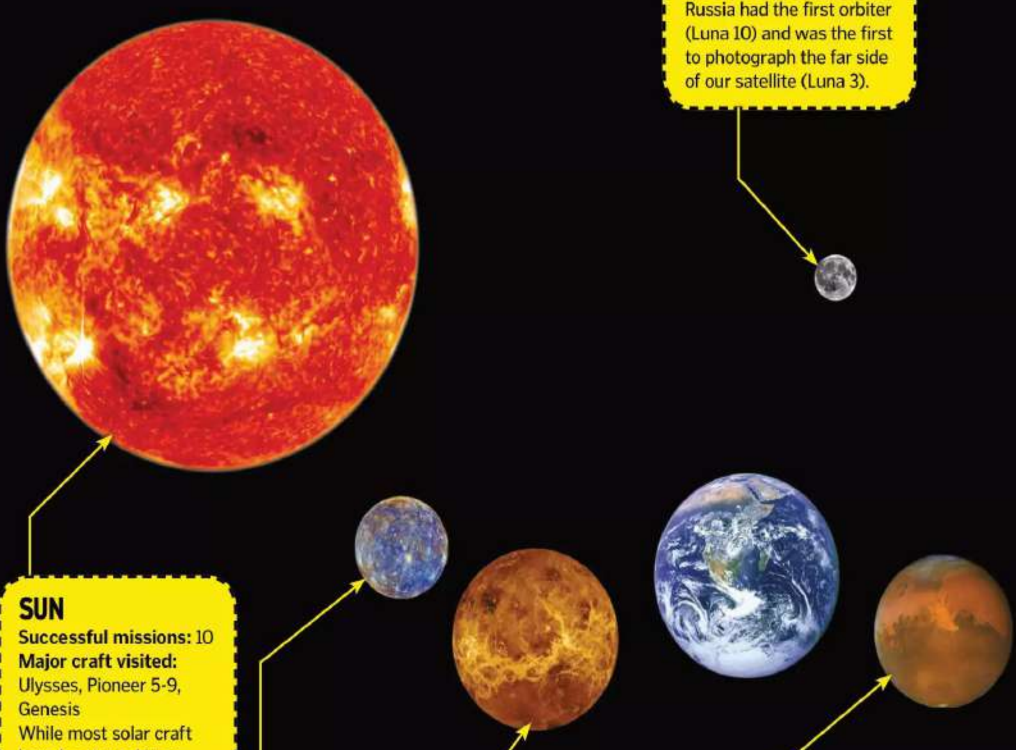
The threat of micrometeoroids – tiny particles weighing less than a gram – is very real, though. They travel at thousands of kilometres an hour and a collision with one is like being hit by a high-velocity bullet, so sensitive areas of the craft are shielded with blankets of Kevlar armour and strong fabric. The lack of atmosphere in space makes the spacecraft's systems prone to temperatures outside their range, so for thermal regulation special heaters are used as well as passive cooling with gold reflectors or white thermal blankets to deflect heat from the Sun.

Dealing with space radiation

As we send more probes farther into space and learn more about our Solar System, the prospect of sending manned missions beyond the Moon is becoming much more realistic. One of the biggest obstacles to this effort is how to protect astronauts from the high-energy particles found in deep space and the deadly solar winds, which contain alpha particles and protons that can destroy DNA, causing cancer. Astronauts in terrestrial orbit, such as those working aboard the International Space Station, are protected by the Earth's magnetosphere, but Apollo astronauts are thought to have got lucky in avoiding the deadly solar maximum on NASA's missions to the Moon. Recently, scientists have been working on a way of using magnets to create an artificial miniature magnetosphere 200 metres (660 feet) around a manned craft that would effectively separate the charge of the solar wind, deflecting harmful particles away. This still wouldn't protect from intergalactic cosmic rays though, meaning a safe manned mission to, say, Mars is still a way off yet.

SOLAR SYSTEM EXPLORERS

TAKE A TRIP THROUGH THE SOLAR SYSTEM TO LEARN WHICH BODIES HAVE RECEIVED THE MOST VISITORS



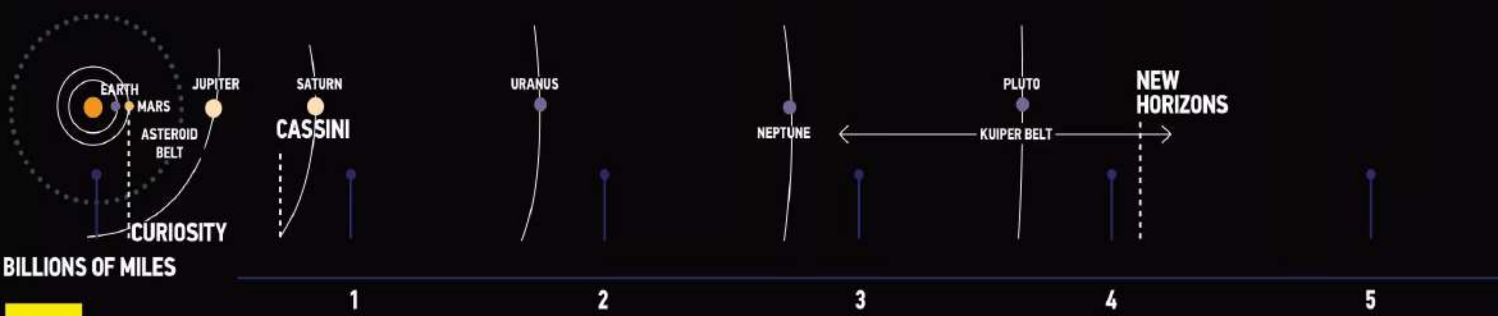
MOON
Successful missions: 65
Major craft visited: Apollo 11, Luna 3, Lunokhod 1
The USA had the first lunar manned mission, but Russia had the first orbiter (Luna 10) and was the first to photograph the far side of our satellite (Luna 3).

SUN
Successful missions: 10
Major craft visited: Ulysses, Pioneer 5-9, Genesis
While most solar craft have been used in an observational capacity, Genesis managed to take a sample of solar wind and then return to Earth.

MERCURY
Successful missions: 2
Major craft visited: Mariner 10, MESSENGER
NASA's MESSENGER is Mercury's first orbiter, assembling an incredibly detailed three-dimensional map of the tiny planet in February 2013.

VENUS
Successful missions: 25
Major craft visited: Venera 7, Mariner 2, Magellan
In 1970, Russia's Venera 7 was the first successful Venusian lander, and it was also the first successful landing on any other planet.

MARS
Successful missions: 26
Major craft visited: MSL Curiosity, Mariner 4, Viking 1
Mars has become the focus of intense scrutiny because of its proximity in the inner Solar System and because of its relatively Earth-like environment.



SPACECRAFT TYPES CONT.

6 SURFACE PENETRATOR

Examples:
Mars Polar Lander, Mars 96
Surface penetrators must survive an acceleration of hundreds of 'g's through the atmosphere to punch their way into a planet, before they can begin to analyse the subsurface composition.

7 ROVER

Examples:
Curiosity, Lunokhod 1
These are sophisticated, semi-autonomous vehicles that can move across the surface of a planet. They're dropped in a capsule so that they survive descent and are fitted with many scientific instruments.

8 MANNED

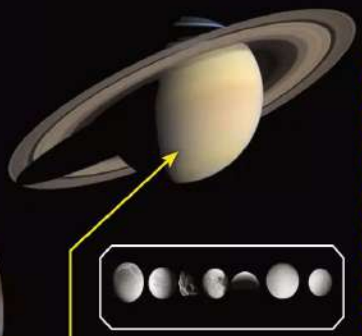
Examples:
Vostok 1, Apollo 11
Historically, these have been orbiters or landers installed with life-support modules to house astronauts and make the return journey to Earth. However, some proposals have included non-return craft with colonisation as a primary objective.

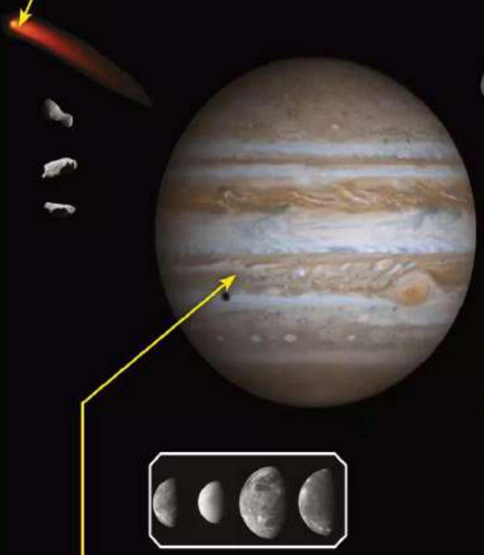
ASTEROIDS/COMETS

Successful missions: 29
Major craft visited: Dawn, NEAR Shoemaker, Deep Impact
The Asteroid Belt is home to Ceres, the only dwarf planet in the inner Solar System. The Deep Impact probe famously shot an impactor into comet 9P/Tempel 1 as it flew by to study its composition.

NEPTUNE

Successful missions: 1
Major craft visited: Voyager 2
As with Uranus, Voyager is the only craft to have visited Neptune, taking photos of unprecedented detail before moving on to become the second-farthest man-made object from Earth – just behind its twin, Voyager 1.





URANUS

Successful missions: 1
Major craft visited: Voyager 2
Having launched back in 1977, Voyager 2 reached Uranus in 1986 before continuing on through the Solar System. It studied the planet's dark rings and found ten new moons.

SATURN

Successful missions: 5
Major craft visited: Pioneer 11, Voyager 1, Cassini
NASA's Cassini became Saturn's first orbiter in 2004, deploying Huygens, the ESA atmospheric probe and lander, onto Saturnian moon Titan in 2005.

PLUTO/KUIPER BELT

Successful missions: 0
Major craft en route: New Horizons
The logistics of getting to Pluto, around 4.8bn km (3bn mi) away, are extremely challenging. Hence, New Horizons became the first craft to reach the dwarf planet in 2015.

JUPITER

Successful missions: 9
Major craft visited: Galileo probe, New Horizons, Pioneer 10
Jupiter's huge gravitational pull is used to 'slingshot' spacecraft into the outer Solar System and beyond, so it has seen many flybys.

WHAT IS THE DEEP SPACE NETWORK?

The establishment of the Deep Space Network (DSN) has been a critical component of many NASA missions. It's a communications system comprising three huge antennas with transceivers strategically positioned around the world: Goldstone in eastern California's Mojave Desert, Robledo de Chavela near Madrid, Spain, and the Canberra Deep Space Communication Complex in Australia. Their terrestrial position means that the collective DSN can communicate with any craft beyond a critical 30,000-kilometre (18,640-mile) threshold from Earth.

This network is used not only to relay and receive telemetry from spacecraft, but also to gather data from probes and transmit commands or software updates. It was recently used to monitor and guide NASA's Mars Science Laboratory probe onto Mars and is in frequent contact with the Curiosity rover as well as using the artificial satellite network orbiting Mars. NASA's DSN isn't the only example of such a communications network though. It often co-operates with other space agency networks, such as the Soviet Deep Space Network and ESTRACK, managed by the European Space Agency.

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